Group Chairman's Factual Report

Engineering

S/S Norway Boiler Rupture

Accident Number: DCA-03-MM-032

Table of Contents

Table of Figures

A. Accident Data

Accident No.: DCA03MM032

Vessel Involved: Passenger vessel *S/S Norway*

Location: Pier 1-2, Miami, Florida

Date: May 25, 2003, 0637

Time: 0637 EST[1]

B. Operations and Engineering Group Representatives

1) National Transportation Safety Board

Engineering Group Chairman: Tom Roth-Roffy
Office of Marine Safety, NTSB
490 L'Enfant Plaza East
Washington, D.C. 20594
Telephone: 202-314-6494 Fax: 202-314-6454 Cell: 202-285-6119
Email: rothrot@ntsb.gov, web: www.ntsb.gov

Assistant Engineering Group Chairman: Brian Curtis
Office of Marine Safety, NTSB
490 L'Enfant Plaza East
Washington, D.C. 20594
Phone: 202-314-6456 Fax: 202-314-6454 Cell: 202-230-8778
Email: brian.curtis@ntsb.gov

Gayl Glascoe (boiler controls)
Naval Sea Systems Command
2798 Harbor Dr
San Diego, CA 92113
Phone: 619-744-1088 Fax: 619-744-1013
Email: GlascoeGL@supship.navy.mil

Bill Ingram (boiler damage survey)
Dept of the Navy
Military Sealift Command, NFAF EAST
PO Box 7480
Virginia Beach Virginia 23458-7480
Tel: 757-417-4359 Cell: 757-434-4414
bill.ingram@msc.navy.mil

John Reddy (boiler damage survey)
Military Sealift Command – NFAF East
Camp Pendelton
P.O. Box 7480, Building 242, 2nd floor
Virginia Beach, VA 23458-7480
Tel: 757-417-4637 Fax: 757-417-4640 Cell: 757-672-5574

[1] All times are in Eastern Standard Time as read on a 24-hour clock, unless specifically noted.

john.reddy@msc.navy.mil

2) Party: U.S. Coast Guard

Ken Olsen
Office of Investigations and Analysis
Commandant (G-MOA-1)
USCG Headquarters
2100 Second St., SW
Washington, DC 20593
Phone: 202-267-1417, FAX: 202-267-1416
Email: kolsen@comdt.uscg.mil web: www.uscg.mil

CDR Chris Oelschlegel
Traveling Inspector, "M" Quality Assurance Staff
Commandant (G-MO-1)
USCG Headquarters
2100 Second St., SW
Washington, DC 20593-0460
Phone: 202-267-0250, FAX: 202-267-4667
Email: coelschlegel@comdt.uscg.mil

MST1 Carlos Paillacar

USCG Marine Safety Office
100 McArthur Way
Miami, FL 33101-6940
Tel: 305-535-8271, Fax: 305-535-8742
cpaillacar@msomiami.uscg.mil

3) Party: Norwegian Cruise Line

Stephen D. Cmar
Manager, Environmental and Regulatory Compliance
7665 Corporate Center Drive
Miami, Florida 33126
Tel: 305-436-4956 Fax: 305-436-4159
Mobile: 786-210-0327
Email: scmar@ncl.com web: www.ncl.com

Chris LK Foong
Vice President, Technical Operations
7665 Corporate Center Drive
Miami, Florida 33126
Tel: 305-436-4828 Fax: 305-436-4135
Mobile: 786-210-0349
email: cfoong@NCL.com web: www.ncl.com

John E. Riley
Riley Marine Survey & Consultancy
535 Ocean Avenue, Suite 10A
Santa Monica, CA 90402

Tel: 310-394-3190 Fax: 310-395-4954
email: RileyMarine@Adelphia.net

4) Party: Bureau Veritas

Michel Lambert
Senior Surveyor, Technical Department – Machinery Section (DT2)
17 bis, Place de Reflets
La Defense 2. 92499 Courbevoie
France
Tel: 33 1 42 42 91 54 73 Fax: 33 1 42 91 53 20
Email: michel.lambert@bureauveritas.com

5) Party: Bahamas Maritime Authority

Kevin P. Hislop, representing Bahamas Maritime Authority
London Offshore Consultants, Inc.
Marine & Engineering Consultants
Principal Marine Engineering Consultant
629 SW 167th Way
Pembroke Pines, FL 33027
Tel: 954-430-5778 Fax: 954-436
email: florida@locamericas.com, web: www.locamericas.com

Capt. Aksel Huus
Safeships Consulting International, Inc.
20826 San Simeon Way #55L
North Miami Beach, FL 33179
Tel: 305-651-0049 Fax: 305-651-7130
Email: hsafeships@cs.com

Andrew Clark
Senior Marine Surveyor
Tel: 954-763-7736
Email: wamcoaclark@coralwave.com

6) Party: Siemens AG, Industrial Solutions and Services, Industrial Plants

Jan Röttingen
Sales Manager, Marine Solutions
Postal address: Siemens, AG, I&S IP 91
Postfach 10 59 09
D-0038 Hamburg
Office address: Lindenplatz 2
D-2099 Hamburg
Tel: +49 40 2889 3214 Fax: +49 40 2889 2734 Mobile: +49 151 12 11 13 29
Email: jan.roettingen@siemens.com

7) Party: Lloyd Werf Shipyard

Werner Lueken, Managing Director
Lloyd Werft GmbH
Brückenstrasse 25
Postbox 120254
27568 Bremerhaven, Germany
Tel: +49 (-471) -478-301, Fax: +49 (-471) -478-280

C. Summary

On Sunday, May 25, 2003, about 0637, the passenger vessel *S/S Norway*, operated by Norwegian Cruise Line (NCL) experienced an explosion in the boiler room. The vessel had entered the port of Miami early that morning, after having completed a 7-day cruise. Before arrival in Miami, the vessel had departed Great Stirrup Cay on Saturday evening, and made an otherwise uneventful transit back to her homeport of Miami. The S/S Norway operated from the port of Miami year round with port calls to St. Martin, St. John, St. Thomas, and Great Stirrup Cay, Bahamas. The vessel could accommodate up to 2560 passengers and 930 crewmembers. The vessel had a steaming speed of 25 knots; however the vessel normally operated at cruising of speed of 17-18 knots during her weekly voyages. The *S/S Norway*, at 1035 feet, was the world's longest cruise ship afloat at the time of the accident.

On the day of the accident, the *SS Norway* commenced reducing speed for her approach to Miami at 0245. At 0305 the bridge notified the engineer on watch in the engine room that the vessel was 5 miles off. The Captain came up to the bridge shortly thereafter and assumed the *conn* from the mate on watch. A Biscayne Bay pilot boarded the *S/S Norway*, three nautical miles east of the MSB (Miami Sea Buoy) and assumed navigational control of the bridge at approximately 0325. At 0334 the *S/S Norway* passed the Miami Sea Buoy, bound for her berth in Miami. The vessel proceeded inbound through Government Cut, transited the main channel and turned about in the turning basin. First line to the pier was at 0515 and the vessel was all-fast at pier 1 / pier 2 by 0530.

At 0529 the deck watch officer logged "Finished M/T [Main Turbines] – Disengaged steering gear and Navigation Lights Off." Due to traffic passing in the main channel the Captain left the thrusters on to keep pushing the *S/S Norway* easy alongside the dock. At 0600, the vessel was finished with all engines and thrusters, and the crew began preparing for her normal Sunday routine in Miami.

Before the accident, the crew of the *S/S Norway* was engaged in their normal duties, some of which included rigging gangways, discharging garbage and preparing for bunkering operations. The bridge team that had assisted in mooring the vessel was standing down and heading to their cabins. The mate on watch was on the bridge along with his relief and was securing bridge equipment for the vessels stay at the pier in Miami. Gangways at Biscayne deck were rigged and attended to by security guards. Some crewmembers were engaged in offloading garbage to the dock from the garbage side port. As a result of the accident, 8 crewmembers were killed and 10 crewmembers were seriously injured.[2] No passengers were killed or injured.

The chief engineer, staff chief engineer, and chief electrician, reported to the engine control room about 0255 for the transit into Miami. During the transit into Miami, three main boilers (nos. 22, 23, and 24) were in

[2] Title 49 CFR 830.2 defines a fatal injury as any injury that results in death within 30 days of the accident. It defines serious injury as that which requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; results in a fracture of any bone (except simple fracturesof fingers, toes, or nose); causes severe hemorrhages, nerve, muscle, or tendon damage; involves any internal organ; or involves second- or third-degree burns, or any burns affecting more than 5 percent of the body surface.

operation and one main boiler (no. 21) was secured for maintenance. According to the chief engineer and two of the engineers on watch in the engine room at the time, the maneuvering into Miami was uneventful. At the end of "standby," the engineers took steam off the main engine, engaged the shaft turning gear, and cut-out one of five oil burners from each of the 3 main boilers that were in operation.[3] The chief engineer, staff chief engineer, and the chief electrician left the engine control room at the end of standby. According to a second engineer who was on watch during the transit into Miami and who was in the aft boiler room about 3 to 5 minutes before the explosion, maintenance work or change in operating status was not underway on boiler no. 23 when he was in the aft boiler room. None of the three crewmembers that were on watch and working in or near the aft boiler room survived the accident.

D. Details of the Investigation

1) Vessel Data

Accident Information	**NTSB NO. DCA03MMA032**
Date of Accident:	Sunday, May 25, 2003
Time of Accident (local)	0637
Location	Pier 1-2, port of Miami
Type of Accident	Boiler explosion
General Information	
Vessel Name	S.S. Norway
Vessel former name(s)	S. S. France
Flag	Bahamas
Port of Registry	Nassau
Owner/Operator Name	Norwegian Cruise Line
Waters (Int'l or Inland):	International
Builder	Penhoet, Chantiers De L'Atlantique
Location built	St. Nazaire, France
Date keel laid	October 7, 1957
Date Launched	May 11, 1960
Date laid up	1974-1979
Official Number	710763
MMSI	308187000

[3] Information based on statement made by second engineer responsible for boiler maintenance on May 27, 2003, during NTSB interview. On scene observations after the accident indicated that boiler 21 was not in operation at the time of the accident because one of its burner registers was removed from the boiler front and operation of the boiler was not possible with a burner register removed.

	Classification Society	Bureau Veritas[4]
	Class No.	21E762 BV
	IMO Number	5119143
	Vessel Particulars	
	Type of Vessel:	Passenger
	Passenger on board	2135
	Gross Tons	76049
	Net Tons	45886
	Length Overall (LOA)	1,035.4 ft
	Waterline Length (LWL)	981 ft
	Length btw perp. (LBP)	951
	Beam	110 ft
	Depth	35.5 ft
	Call Letters	C6CM7
	Propeller No.	Twin Screw / Five Thrusters (3 forward, 2 aft)
	Propulsion type	Steam. Four Boilers, Two Steam Turbines, 40,000 SHP, geared reduction
	Electrical Power	Six Steam Turbo Generators
		Five Aux. Diesel Generators
	Crew	
	Number Total	911
	Deck Officers	9
	Engine Officers	17
	Vessel information	
	Fuel on Board	2396 MT Heavy Fuel (380 cSt)
	Diesel	171 MT
	Lube Oil	94 MT
	Fresh Water	1930 MT
	Draft Fwd	10.74 m
	Draft Aft	10.67 m

[4] At the time of the accident BV was the classification society. American Bureau of Shipping (ABS) surveyed the vessel while it was being built and during its first years of operation. Det Norske Verita (DNV) was the classification society that performed the ISM verification on behalf of Bahamas.

.	**Machinery Information**	
	Main Boilers (4)	Evaporation rate: 71.5 tons/hr
		Working pressure, stm drum: 71.5 Kg/cm2
		Max superheater exit pressure: 64 Kg/cm2
		Max superheater temperature: 500 deg C

2) <u>Boiler description</u>

a) The main propulsion boilers were of the water tube, bent-tube, single-furnace, integral-superheater type (see figure 1). They were a modified D-type, in that, unlike standard marine d-type boilers, the boilers on the *Norway* had a large diameter waterwall header (29 inch diameter) with manhole covers at each end.[5] In addition, the waterwall headers were constructed with a similar design as the water drum, in that a tube sheet and wrapper sheet comprised the cylindrical structure.[6] The wrapper sheet and the tube sheet were joined by longitudinal welds. The size of the elliptically shaped manhole openings of the waterwall header were 30 cm by 40 cm (approx 12 in by 16 in), and as a result entry was difficult for persons with average or above average body size.[7] The water drum and waterwall header were located below the deck plates of the operating platform.

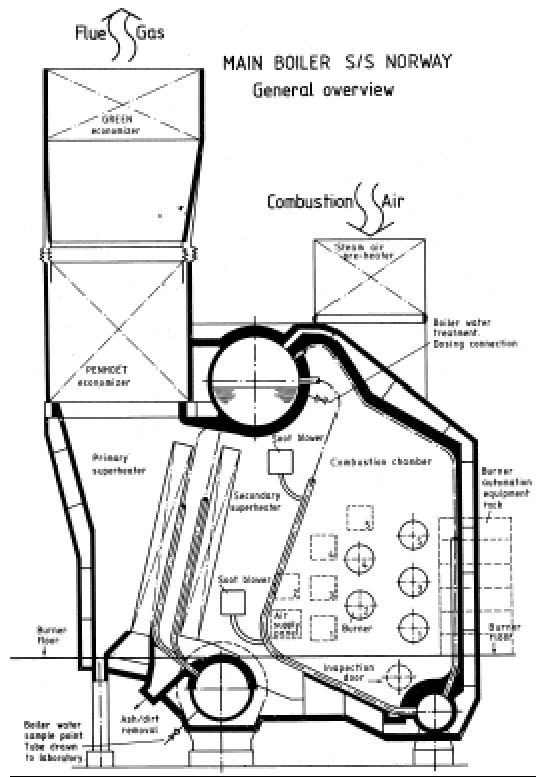


Figure 1 - Boiler cross-sectional view

The boilers produced steam at about 60 bar (870 psi) pressure through the transfer of heat from burning fuel in the furnace to the water-filled tubes that surrounded the furnace and that were in the path of hot combustion gases. The tubes were arranged in rows at high angles of inclination in order to provide accelerated natural circulation of the water in the boiler between the steam drum and the water drum. The tubes, which varied in diameter from about 1 inch to about 4 inches, were arranged in named banks, and included generating tubes, screen tubes, downcomer tubes, superheater tubes, waterwall tubes and floor tubes. The generating tubes were the largest in number and were where the greatest portion of the steam was produced. The screen tubes were of a larger diameter than the generating tubes and protected the

[5] According to the Society of Naval Architects and Marine Engineers (SNAME) publication *Marine Engineering*, a header is defined as a “drum too small to permit entry through a manhole,” and therefore the component is more properly termed a waterwall *drum* since entry was possible. However, this report uses the term waterwall *header* rather than waterwall *drum* because it follows traditional terminology for the component, and because it was the term used by crewmembers aboard the vessel.

[6] According to USCG regulations (46 CFR Part 52), a waterwall is a “series of tubes or elements spaced along or integral with the wall of a furnace to protect the wall and provide additional heating surface.” Also, a header is a “hollow forging, pipe, or welded plate of cylindrical, square, or rectangular cross section, serving as a manifold to which tubes are connected.”

[7] In NTSB witness interviews, the second engineer, who was a bit larger than average, said he could and did enter the waterwall headers, the alternate or relief chief engineer who was 6 ft-07 in and 340 pounds, said that it was impossible for him to enter the drums and headers. In addition, the classification society surveyor at the time of the accident stated that he could not physically enter the drums and headers.

superheater tubes and generating tubes from direct exposure to the radiant heat from the flames in the furnace. The waterwall tubes and floor tubes provided water cooling of the boundaries of the furnace. The downcomer tubes were of the largest diameter, were installed outside the furnace area, and served to ensure adequate downward circulation of relatively cool water between the drums. The steam drum served as the upper interface between the steam and water, and had internal devices to assist with the separation water droplets from steam before it exited the steam drum. At the top of the steam drum was the steam outlet pipe, from which the steam was routed to another set of tubes called the superheater, in order to further raise its temperature and, therefore, its heat content or enthalpy. The superheater tubes were arranged in a horizontal orientation, and were located after the screen tubes in the exhaust gas flow path. The superheating of the steam output was a constant pressure process, although the pressure was reduced as it passed through the superheater as a result of flow losses that varied with the steam flow rate.

Burning of the fuel oil was accomplished by introducing pressurized heavy fuel and combustion air at the fuel oil burner assemblies mounted the front side of the boiler. The each boiler had 5 fuel oil burners that could be operated as needed in response to changes in steam demand. The fuel oil burner assemblies were fully automated to allow starting and stopping of the burners through either manual pushbutton control or by the automatic burner management system.

The outer surfaces of the boiler were kept cool by the use of water-cooled furnace walls (waterwall tubes) and refractory materials suitable for high temperatures. In addition, the boilers had a steel inner and outer casing between which combustion air was routed from the forced draft fans to the fuel oil burners, which served to further reduce the heat transfer rate to the outer surface of the boilers and increase the temperature of the combustion air.

The boilers were designed to operate at 71.5 kg/cm^2 (1016 psi) drum pressure, but were normally operated at about 60 to 62 bar.[8] No documents could be found to indicate when and why the operating pressure had been reduced, and the former port engineer, who was associated with the *Norway* from 1981 until 1999, could not provide any insight. He stated that he could not “recall that … I think it was done all the way back when they picked up the boiler in France and they put it into operation … for what reason, I don't know.” In addition, the current classification society boiler certificates indicate that the boilers were rated for an operating pressure of 71.5 kg/cm^2.[9]

The boilers were oil-fired (heavy fuel oil), forced draft, and were fitted with five burner assemblies on the front of the boilers. The boilers had two-stage (primary and secondary), horizontal superheater tubes. Each boiler had two economizers: the upper bank had finned tubes and the lower bank had bare tubes. Each boiler was supported by foundations at its under side. The waterwall header, the water drum, and the inboard side of the boiler structure each had one structural support at the forward and one at the rear end of the boiler. The structural foundations were designed to allow thermal expansion of the boiler (resulting from light-off and shut down) by the provision of elongated holes for the bolts connecting the boiler to the foundations. The orientation of the elongated holes in the foundation were in the direction of expected expansion. This design arrangement was known as a sliding foot. Additional mechanical stresses are usually be imposed on a boiler if the sliding feet do not move as designed, and it is recommended that movement of the sliding feet be verified when the boiler is lit-off.[10] [11]

[8] The original *S/S France* boiler operating and maintenance manual states that superheater pressure should be regulated to between 60 and 64 kg/cm^2, and “at anchor, operation at reduced pressure, 45 kg/cm^2, for example, is possible without difficulty.”

[9] According to a classification society witness interview by the Safety Board on Jun 11, 2003, an operator could operate a boiler at any pressure below rated pressure without approval from the classification society.

[10] U.S. Naval Ships Technical Manual (NTSM) Chapter 221 (221-2.15.1) states “The sliding foot movement indicators shall be inspected before light-off, during boiler warm-up and after the boiler is on the line, to verify that movement of the water drum and lower headers is not impeded by defective sliding feet. The navy technical manual for repair and overhaul of main propulsion boilers (S9221-CI-GTP-020) at section 12-1.2, states “The movement in a sliding foot occurs between the saddle base plate and the phosphorous bronze chock facing. These

The boilers were fitted with two safety valves on the steam drum, one safety valve on the superheater and a superheater pilot valve (mounted on the steam drum). According to BV rules, the relieving capacity of the safety valves must be adequate to relieve the maximum steam generation capacity of the boilers.[12] Two safety valves fitted at the top of the steam drum were set to release at 71.5 and 71.3 kg/cm2 (1017 and 1014 psi). The third safety valve installed at the superheater outlet was set to release at 66 kg/cm2 (939 psi). The superheater safety valve could either release spontaneously at its set pressure or have its action intiated by a pilot valve mounted on the steam drum that was set at 71 kg/cm2 (1010 psi).

b) The boilers were fitted with an electronic automatic control system *and* an electronic boiler management system. For both of these systems, a local operating console was installed in the aft boiler room, and the main system electronics were installed in the engine control room (ERC). The functional elements of the control system were water drum control, fuel oil flow control, combustion air control, superheater temperature control, load control, fuel oil viscosity control, fuel oil pressure control, and feedwater pump control. The boiler management system provided the operator with automatic light-off and shut down sequencing of the boilers and burners. The automatic sequencing system was only in use for heavy fuel oil operation and not with diesel oil firing during cold boiler start-up. In addition, it functions as the boiler safety system to automatically shut down the boiler or burners when critical parameters exceed safe limits or flame failure occurs. In addition to these control systems, a remote monitoring and alarm system was fitted to the boilers. The alarm system had various temperature and pressure alarms that would alert the operating engineers of abnormal conditions. Alarm conditions were automatically stored and printed out for later review by the operating engineers.

Figure 2 - Boiler strip chart recorders

Several monitored parameters were continuously recorded on chart recorders (see Figure 2). The parameters recorded were steam drum level, steam drum pressure, fuel oil pressure for burner, fuel oil flow, superheater steam pressure, and superheater steam flow. In addition, various automatic safety shutdowns, such as low water level in the boiler steam drum and high steam pressure,[13] were fitted to protect the equipment and personnel from damage.

c) Boiler characteristics. According to the boiler manual, the boilers had the following design characteristics:

surfaces must be kept clean and lubricated to ensure movement. A sliding foot that cannot move is termed a “frozen foot” and causes high stresses on the foundation and ship structure because it restricts boiler expansion.”

[11] Det Norske Veritas (DNV) guidance in its newsletter *Classification News* no. 2. 2004, states “For boilers with sliding feet, the marking patterns will be verified in order to confirm whether or not the boiler expands freely during operation.”

[12] BV Rules (Part C, Chapter 1, Section 3), state “the aggregate capacity of the safety valves is to be such as to discharge all the steam that can be generated without causing a transient pressure rise of more than 10% over the design pressure.”

[13] The vessel’s chief engineer stated in a May 26, 2003, interview that the boiler would shut down if the pressure reaches 62 bar.

I - GENERAL DESCRIPTION

The steam generation plant of the liner "France" consists of 8 Penhoët natural circulation boilers with the following principal characteristics :

- maximum evaporating capacity	90 T/H
- corresponding fuel consumption	6.500 Kg/h
- working pressure	71,5 Kg/cm^2
- maximum pressure at superheater exit	64 Kg/cm^2
- maximum superheat temperature	500°C
- feed temperature	120°C
- combustion chamber volume	51,4 m^3
- direct heating surface	93 m^2
- bricked surface	24,4 m^2
- convection heating surface	416 m^2
- primary superheater surface	248 m^2
- secondary superheater surface	248 m^2
- Green economizer surface	513 m^2
- Penhoët economizer surface	559 m^2
- Air heater surface	1.560 m^2

3) Basic steam cycle

The steam cycle was based on the familiar thermodynamic Rankine Cycle. The steam cycle is a closed heating cycle that consists of four distinct phases: generation, expansion, condensation and feed (see figure 3). The steam cycle is termed a closed cycle because the steam output is condensed and returned to the boilers as feedwater and then reused in the generation of steam. The ship's boilers were in the generation phase, serving as the devices that converted the fuel oil's chemical energy into thermal energy (steam).

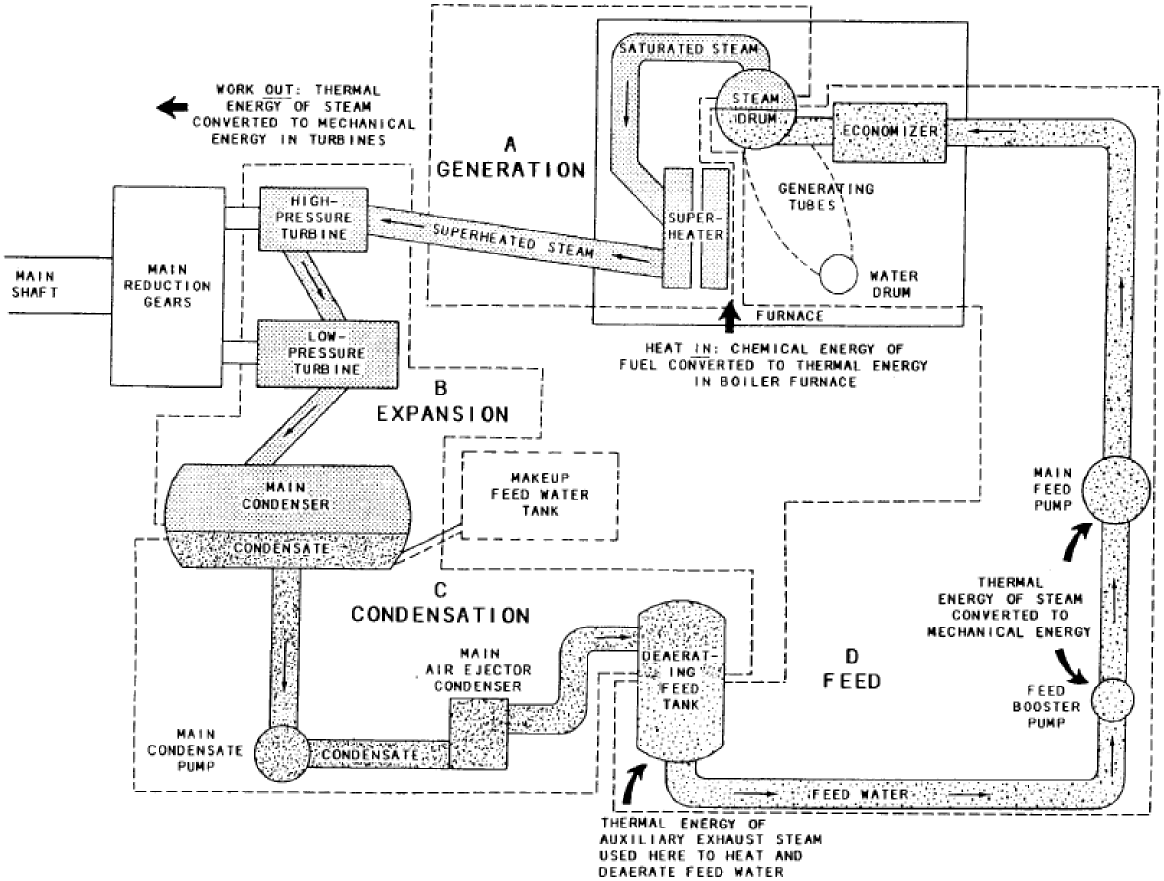


Figure 3 - Basic Steam Cycle

The other major components in the steam cycle, in the expansion stage, were the devices that converted the thermal energy into mechanical energy. These components were the main propulsion turbines and the auxiliary turbines, used to drive the ship’s propellers and electrical generators. As the steam passes through the rows of blades in main and auxiliary turbines, the steam progressively expands, cools, and transfers energy to the turbine rotors. The turbines rotational mechanical energy is then used to drive their connected loads. Other users of the steam were heat exchangers that served to heat the boiler’s fuel oil, produce distilled water, and to heat the living and workspaces on the ship, among other auxiliary uses.

As the steam leaves the turbines, now in the condensation stage, it is at a very low pressure (high vacuum) and a much lower temperature that when it entered. The low-pressure steam’s phase is changed from a vapor to a liquid in a seawater-cooled condenser. The condenser serves to receive the low-pressure steam, condense it on water-cooled tubes, and collect the condensate for delivery to the suction side of the condensate pump. The condensate pump increases the pressure of the fluid, and delivers it to the dearating feedwater heater, where the water is heated through a direct contact with steam. The water temperature is raised and entrained gases, most importantly oxygen, are removed.

The heated and dearated water, now called feedwater, is led to the feedwater pump where it pressure is increased to above boiler pressure. From the feedwater pump, the water is passed through the economizer tubes located in the uptake area of the boiler where it receives additional heat from the boiler exhaust gases, and is them led into the steam drum below the water line, where the steam cycle begins again.

4) Boiler History

a) The main boilers on the vessel were installed when the vessel was originally built. The vessel was fitted with eight boilers in two separate compartments – the forward boiler room and the aft boiler room. The vessel was in a lay-up period from 1974 to 1979 during which boilers 21, 22, 23, and 24 were in a lay-up status. The classification society specified procedures for preservation of the layed-up boilers.[14] During a conversion/overhaul in 1979-1980 by the Norway's present owner,[15] the four boilers in the forward boiler room were removed, leaving only the four boilers in the aft boiler room to supply steam to the main propulsion turbines and auxiliaries. Also, during the overhaul/conversion in 1980, a new automatic boiler control system was fitted to the boilers and the boiler rating (steam flow rate and pressure) were reduced. In addition, one of six burners was removed and the arrangement of the burners was modified.[16] According to a study that was done in 1983, the boiler capacity was excessive and a recommendation was made to lower it from 90 tons/hour to 60 tons/hour.[17]

b) Marine boilers are designed to operate for a specific number of cycles or hours. The degree of material fatigue on a boiler, while affected by many different factors including a comprehensive inspection and maintenance program, is an any event limited to the designed cycle life. According to a representative of Siemens AG familiar with boiler design, usually, a marine boiler of this size is designed to operate for 100,000 hours plus fifty percent. Testing of the boiler drums done by DNV for NCL indicated that the boiler drums had undergone significant material degredation. See section for further discussion of testing done.

c) <u>Major overhaul</u>. According to the boiler 2nd engineer and maintenance records, the last major work done on the boiler was retubing of the generating tube bank during the May 1999. In addition, retubing of the secondary superheater was done during the normal operating period of the vessel, in 2002. In addition, both upper and lower economizers were retubed in November 1998. The drums (steam and water) and waterwall headers had never been changed in any of the four boilers.

d) <u>Tube failures</u>. All boilers had experienced numerous instances of tube failures over their lives.[18] The vessel operator had the failed tubes analyzed on several occasions. In 1981 all boilers experienced significant failures of tubes, and the cause of the failures was attributed to contamination from sulfamic acid that had inadvertently found its way into the boiler feedwater system.[19] Analysis of failed tubes was also undertaken by the boiler water chemical company on several occasions.[20,21].

e) <u>Cracks and pits</u>. According to records received by the board from the classifications society and the vessel operator, cracks were first discovered and repaired in the boiler drums at least as early as 1970 and 1973.[22] Cracks were documented again in 1982,[23] 1984,[24] and 1987.[25] In 1987, boiler

---

[14] Report of layup procedures is contained in a Duetsche Babcock summary of the boiler history, dated September 18, 1985. The instructions required 1 to 2 mg/l hydrazine to be maintained during the wet layup of the boilers.
[15] The name of the company at that time was Klosters Rederi A/S..
[16] According to the chief engineer, (in his May 26, 2003 NTSB interview), the pressure of the boilers was lowered from 64 to 60 bars, and the output capacity was reduced about 20 percent.
[17] Report of the Norwegian Steam Association, dated 14 April 1983, concluded that the "optimal loading is, therefore, 60 tons/hours and minimal load variations."
[18] See engineering time line for details of boiler tube failures .
[19] 1981 Nov 18 owners statement claims that the damage was caused by sulfamic acid entering the boiler feed water system as a result of leakage from one of the evaporators.
[20] 1996 Sep 03 Drew Marine analysis report attributed a boiler no 21 tube failure to "the dual contributions of internal stess-assisted corrosion damage and creep void and crack formation, which was related to long-term metal overheating. The long service of the boiler tube in a high radiant heat section, the metal bending, cyclical nature of the boiler, and the presence of internal deposits were likely the root causes of the observed problems in the boiler tube."
[21] 1981 May 13 Drew Marine report of analysis of boiler tube failures relating to sulfamic acid incident.
[22] According to a Deutsche Babcock report of Boiler history dated September 18, 1985, states that classification society found cracks in Dec 1970 "small flaws in the welded seams in the water part of the upper drums, max depth 1.5 mm, and in Dec 1973 cracks were found that were 1-3.5 cm, and were ground off up to 3 mm depth.

no. 21 was restricted in its operation because of the severity of the cracks in the upper and side drums (waterwall header) until they could be repaired by welding,[26] which was completed in while the vessel was at sea in November 1987.[27] A weld procedure was created and performed by Duetsche Babcock as a subcontractor to Lloyd Werf in the shipyard and approved by the classification society BV. Cracks were again documented to be found in 1990[28] and 1996.[29] Welding was again done on several drums and headers in drydock at Lloyd Werft shipyard by NCL contractors in 1990. No documents were found that indicated cracks had been found or repaired after 1996. According to the former port engineer of the vessel, it had been his practice to have the boilers inspected periodically for cracks, but that such inspections did not take place during the 1999 shipyard period, the last year of his employment with Norwegian Cruise Line.[30]

f) Corrosion. Various inspections have found corrosion problems in the boilers. In 1985 strong corrosion pitting and heavy oxygen corrosion was found in all drums a recommendation was made to address the findings.[31] Corrosion was again noted in 1993.[32] In late 2002, a contractor inspected boiler no. 21 at the request of the operator and found "oxygen tubercles present in the [generating] tubes." The report further stated that "what gives us cause for concern is the fact that we do not know what active corrosion is underneath the tubercles."

g) Corrosion warnings. Several documents found indicated that warnings action needed to address the suspected cause of the active corrosion found in the boilers. A January 25th, 1991, memo from a shipyard that had performed an inspection of the boilers stated:

> Regarding the increased occurrence of corrosion pittings inside the boiler drums and Babcock's report on this matter, we hereby point out to you again that the preservation of the boilers in shutoff condition should be given the utmost attention. It would be recommended to make a provision for transfer pumping of the boiler water from the smaller side drums to the upper drum. Maybe, there

---

[23] According to a Deutsche Babcock report dated September 18, 1985, in May/June 1982 corrosion cracks were found in the longitudinal and circumferential welds of the boilers 21-24 by means of magnetoflux. The defective areas mentioned were rectified by means of grinding.

[24] According to a classification society boiler survey report dated September 24, 1984, cracks found and ground, no new cracks found, and "upper and lower drums opened up for inspection and found without new cracks. Lower small drum: cracks were stated in way of the outer and inner longitudinal weld seams, max depth about 2.5 mm. All cracks ground off."

[25] Classification society survey report dated Sep 27, 1987 states that cracks and pitting were found in most drums of all boilers. Cracks were repaired by grinding, except boiler 21 which reached minimum wall thickness and could not be ground further.

[26] Classification society (BV Hamburg) attestation stated that temperature variation rate of boiler 21 to be divided by a factor of two during start up and shut down, care to be taken to soften transients during maneuvers, and access of personnel to the boiler room to be limited to the minimum.

[27] Classification society survey report dated November 21, 1987 stated that cracks and wastage in boiler no. 21 upper drum and side drum were permanently repaired by welding.

28 Babcock test report dated Sep 30, 1990, states that nearly all drums had corrosion and pitting. Report indicates that welding was done nos.22 and no. 23 lateral drum. Report indicates that only boiler no.21 upper drum longitudinal weld was not reworked. Boiler no.23 lateral drum observations reported as: crack-like indications in longitudinal welds, and no crack-like indications in circumferential welds.

[29] September 1996 BV Visa No.5 and Boiler Survey Reports indicated that pitting and cracks were found boiler no. 22 and no. 24. At the time of the inspection scanning found the cracks to be approximately 5 - 6mm deep with a width up to 1 - 1.5mm.

[30] NTSB interview with former port engineer of *Norway*, Jun 12, 2003.

[31] Deutsche Babcock Werke AG Report dated September 18, 1985, stated that all drums of boiler no. 23 show strong corrosion pitting. As only boiler 23 was available, it was assumed that boilers 21, 22, and 24 are in the same state, and that checking of these drums was urgently required. A conclusion was reached that heavy oxygen corrosion was present.

[32] September 16, 1993 report by Geschaftsbereich Service reports finding of corrosion in all drums of boiler no. 24 and recommends followup reinspection at shutdown. In the intermediate drum, severe corrosion pitting on both longitudinal welds which does not extend below the minimum thickness, is noted.

> should also be discussions with Drew Chemical about the dosage of hydrazine in boiler water and condensate.

In July 1991, the same shipyard stated in a memo:

> Please find enclosed the report of the boiler water analysis for the S/S Norway.... No major trace elements have been found in the analysis results. So there is every indication to suppose that the increase in corrosions is nothing else but the effect of shutdown corrosion. We would suggest the following measures to solve this problem: Installation should be done of a connecting steamline from the atomizer steam groups on each boiler to the respective two lower drums in each case. ... The steam as nozzled this way will keep the boiler under pressure and maintain temperature. ... The overall situation about the problems with combustion air and corrosion should be discussed in detail between Siemens, Babcock, the Owner and Lloyd Werft.

h) <u>Operator recent knowledge of cracks</u>. According to crewmembers interviewed by the Safety Board, none had ever seen any cracks nor had any knowledge of a historical problem with cracks on the drums and headers. Additionally, none had any knowledge of any weld repairs that had taken place in any of the drums or headers. When questioned, the second engineer in charge of the boiler maintenance for the past 11 years denied any knowledge of welding repairs or cracks:[33]

Q: Do you recall the last time that welding was done inside of that header?
2nd Engr: I never seen welding inside the header, only on the plugs.
Q: Only on the plugs?
2ND ENGR: Yeah.
Q: Do you recall if anybody discussed any welding that had been done on the header with you?
2ND ENGR: I never heard about that.
Q: Never heard of any welding having ever been done?
2ND ENGR: Never heard of it.

Later, in the same interview, the 2nd engineer stated:
Q: Have you ever been told about a crack -- cracking of the drums, historical problem in the past --
2ND ENGR: No.
Q: -- where --
2ND ENGR: No.
Q: -- somebody had found any cracking --
2ND ENGR: No.
Q: -- in any of the headers or drums?
2ND ENGR: No, never heard about it.

Similarly, when the alternate chief engineer, who had worked aboard the *Norway* since 1993, was questioned about his knowledge of boiler cracks, he disclaimed any knowledge of any historical problems with cracks. Specifically, he stated:

Q: Did anyone ever under any situation talk about fractures or did you ever overhear anyone discuss fractures or cracks or important problems with the boiler weld seams?

A No. Not whatsoever.

However, the port engineer, who had been assigned to the *Norway* from 1982 until 1999, stated that the cracks in the boilers drums and headers were well known by him and others aboard the vessel. Specifically, he stated that all of the chief engineers and the captains aboard the *Norway* were aware of the historical problems with cracks in the boilers.[34] He also said that engineers who were aboard the vessel before 1990 should have known about the cracking problem in the boilers. However, he also

[33] NTSB interview of boiler second engineer on Jun 6, 2003.
[34] NTSB interview of former port engineer of the vessel, Jun 12, 2003.

stated that the primary focus of the crew had been toward tube failures rather than cracks in the drums and headers.

The vice president of technical operations at the time of the accident, who had been in his position since February 2003, stated that, at the time of the accident, he was not aware of the historical problems with cracks in the drums and headers.[35]

5) Management oversight.

a) The *Norway* was owned and operated by Norwegian Cruise Line (NCL), a subsidiary of Star Cruises, PLC, a Malaysian corporation. According to information on the Star Cruises website, "Star Cruises, the Leading Cruise Line in Asia-Pacific was incorporated in September 1993, representing a bold initiative to tap Asia-Pacific's potential as an international cruise destination. Following the acquisition of NCL Holdings in early 2000, Star Cruises is now the third largest cruise line in the world presently operating a combined fleet of 18 ships with over 23,000 lower berths."[36] Five vessels operated under the Star Cruises brand in Asia Pacific – the SuperStar Virgo, SuperStar Gemini, Star Pisces, MegaStar Aries and MegaStar Taurus. The NCL group operated a fleet of twelve ships under two brands: Norwegian Cruise Line, and Orient Lines. The NCL fleet included the Norway, Norwegian Dream, Norwegian Majesty, Norwegian Sea, Norwegian Sky, Norwegian Wind, Norwegian Sun, Norwegian Dawn, Norwegian Star, Norwegian Crown and Norwegian Spirit. Orient Lines was a single ship line with the Marco Polo offering niche destination-focused cruises.

b) In compliance with international regulations (ISM Code), in 1998, NCL had implemented a Safety and Environmental Management System[37] (SEMS), that described the management structure of the company (see figures section E), as well as prescribed the procedures required by the ISM code. Oversight of vessel operation, maintenance, and repair was performed by the senior vice president of Marine Operations under the supervision of the president. According to his position description, other duties of the senior vice president of Marine Operations were to manage overall planning his department, which included Technical, Nautical, Port Operations, New Building & Hotel Refurbishment, Marine Communications, Amos, Intranet Web & SEMS. The senior vice president of marine operations declined to make a statement to Safety Board investigators. The vice president of Technical Services, assisted by his subordinate technical superintendents (previously known as port engineers), was responsible for all aspects of the operating ships technical operations and maintenance; and for the planning, coordination and execution of dry dockings.

c) The *Norway*'s ship superintendent at the time of the accident was a former chief engineer of the Norway, and had been assigned to the vessel since 1999. His predecessor, also a former engineering officer on the Norway, had been assigned continuously as the Norway's port engineer from 1981 to 1999. The vice president of Technical Services had been in his position since February, 2003, and his billet had been vacant at least for the previous 18 months. During the position vacancy, the senior vice president of Marine Operations performed the duties of the vice president of Technical Services, in addition to his other normal duties.[38] The current port engineer of the *Norway* declined to make a statement to Safety Board investigators.

d) At the shipboard level, management of the Norway's engineering equipment was done by the chief engineer and his staff. The chief engineer reported to both the ship's master and the technical superintendent in the performance of his duties. According to his position description, the chief engineer

[35] Safety Board interview of vice president of technical operations on Nov 21, 2003.
[36] Website at http://www2.starcruises.com/Investor/index.html
[37] The ISM code took effect for passenger vessels such as the Norway commencing in 1998. According to the SEMS introduction, the "Norwegian Cruise Line's Safety & Environmental Management System (SEMS) is designed to ensure that conditions, activities and tasks both ashore and onboard essential for the safety and protection of the passengers, crew, ship and the environment, are carried out under controlled conditions. These conditions include: procedures, operating practices, check lists, work permits, training, work verification and assignment of duties to suitably qualified personnel."
[38] NTSB interview of vice president of Technical Services on Nov 21, 2003.

had "full responsibility of the entire technical operation of the ship," and has the "overall responsibility in ensuring that the vessel is operated and maintained to the highest possible standard."[39] Assisting the chief engineer in the performance of his duties were the engineering department crewmembers, consisting of approximately 83 to 87 persons.[40] Each member of the engine department was assigned to the vessel for 10 weeks (one contract). Normally, if the crewmember wished to return to the vessel he could take 10 weeks vacation and then return to his previous or an upgraded position in the engine department for an additional 10 weeks, and could continue with a 10 week on – ten week off rotation indefinitely, provided his performance was acceptable to the chief engineer and captain.[41]

6) Boiler maintenance and inspections by the operator

a) Responsibility for the proper operation, maintenance, and inspection of the vessel and its equipment rested with the operator of the vessel.[42] Generally, in the operation and maintenance of specific systems and equipment aboard the vessel, the operational managers or of a vessel used the recommendations of the equipment and/or system manufacturer, as well as their own judgment based on experience and standard marine practice. International regulations require that passenger vessel operators have a program for the maintenance of shipboard equipment.[43]

b) NCL had a computer-based preventive maintenance program that was used to plan and document maintenance actions.[44],[45] According to the former port engineer of the *Norway*, the computer-based preventive maintenance program was implemented on the *Norway* around 1986 or 1987.[46] The main boilers were covered by the maintenance program, however, no requirement or procedures could be found in the system addressing periodic inspection of the boiler interior areas.

c) The routine operation and maintenance of the vessel's mechanical and electrical equipment, including the main boilers, was performed by the engine department crew of the vessel, under the supervision of the chief engineer. The engineering crew was composed of watchstanders and dayworkers. The dayworkers performed maintenance and repair work during the day shift and were not responsible for performing watchstanding duties. The watchstanders, conversely, worked a 4 hours on 8 hours off shift in the engineering spaces, and were responsible for operating and monitoring the equipment in the engineering spaces during their assigned watch. In addition, each of the engineering

[39] NCL SEMS Procedure C302.2.9, chief engineer position description.
[40] NTSB interview with second engineer for boilers, conducted on May 27, 2003.
[41] Information regarding work schedule rotation is based, in part, on information from interview of vessel's chief engineer on May 26, 2003.
[42] Traditionally, many operators may feel that they share responsibility for these functions with the classification society, the ISM Code clearly assigns responsibility to the operator. The code defines the "Company" as "the owner of the ship or any other organization or person such as the manager, or the bareboat charterer, who has assumed the responsibility for operation of the ship from the shipowner and who, on assuming such responsibility, has agreed to take over all duties and responsibility imposed by the Code." Among other requirements, the code requires that the "Company" "should develop, implement and maintain a safety management system which includes the following functional requirements: instructions and procedures to ensure safe operation of ships and protection of the environment in compliance with relevant international and flag State legislation."
[43] Section 10 of the ISM code states that "the Company should establish procedures to ensure that the ship is maintained in conformity with the provisions of the relevant rules and regulations and with any additional requirements which may be established by the Company. In meeting these requirements the Company should ensure that inspections are held at appropriate intervals; any non-conformity is reported with its possible cause, if known; appropriate corrective action is taken; and records of these activities are maintained."
[44] According to the NCL SEMS Procedure J100, "This ship is to be maintained in compliance with applicable Flag State, Classification, International and Local Rules and Regulations at all times. A Planned Maintenance System, AMOS-D, forms the basis for the onboard maintenance program for equipment and systems, additionally, these shall be an ongoing maintenance program kept up to date both for corrosion control purposes and to present the vessel in a first class condition at all times."
[45] NTSB interview of boiler 2nd engineer on May 27, 2003 indicated that AMOS computer program was used for maintenance of boiler, and that the system was maintained by the senior 1st engineer.
[46] NTSB interview of former port engineer of *Norway*, Jun 12, 2003.

watchstanders (both licensed and unlicensed) was assigned responsibility for the maintenance of specific pieces of equipment during their off watch time, and they were expected to work and additional 2 to 4 hours per day on such duties after their normal watch tour. One of the watch engineers (a licensed second engineer) was assigned responsibility for overseeing the operation and maintenance of the main boilers, and this engineer, at the time of the accident, was assigned to the 8 to 12 watch. These responsibilities did not include the chemical testing and treatment of the water in each operating boiler on a daily basis, as they were done by another second engineer who was assigned to the 12 to 4 watch. The performance of repair work on the boilers was coordinated by the first engineers (first engineer senior and first engineer junior). Under the supervision of the first engineer junior were unlicensed crewmembers (mechanics and other less skilled workers), who actually performed any required cleaning and repair work on the main boilers that were within the capabilities of the ship's crew but in excess of the ability of the boiler second engineer to perform by himself.

d) Shipyard repairs. Repairs that were beyond the capabilities of the crew were normally performed by outside contractors, either during the normal operating schedule of the vessel, or during shipyard repair periods done approximately every 2 years. Documents indicated that the vessel had been in shipyard dry dock at Bremerhaven, Germany, in November 2001, and May 1999, and at Southhampton, U.K., in September 1996. The vessel was scheduled for a dry docking overhaul sometime later in 2003. Some major work was done outside of shipyard repair periods; documents indicate that several boilers had been partially retubed during the normal operating schedule.

e) Maintenance procedures. The original French boiler manuals (translated version) specified that boiler inspection and cleaning should be done at 3000 hour intervals.[47] According to maintenance records and statements by the engineering crew of the Norway, the boilers were cleaned and inspected at approximately 3000 hour intervals. According to the engineering officer who was responsible for the maintenance of the boilers, the maintenance action included cleaning (water washing) the generating, superheater, and economizer tubes, cleaning of the soot, and repairs to the furnace refractory.

f) Cleaning and inspection by crew. Maintenance documents and statements by the vessel's crew indicate that boiler no. 23 had been cleaned and inspected by the crew about 10 days before the accident. According to the boiler 2nd engineer, the work done to the boiler included rebuilding of damaged furnace refractory (blue-ram)[48], cleaning the water economizer, and water washing the superheater and generating tubes. The boiler was off-line for nearly 3 weeks (April 19 through May 14), partly because of an onboard shortage of blue-ram and the crew having to wait for delivery of blue-ram form shore.[49],[50] Records also indicate that boiler no. 23 was cleaned and inspected in January 2003,[51] July 2002, May 2002, September 2001, March 2001, November 2000 and February 2000. Maintenance records indicate that in January 2001, boiler no. 23 experienced failure of several tubes (leaks) that were plugged by the crew.[52] When questioned about repairs that had been done to boiler no. 23, the

[47] Liner "France" Propulsion Machinery, Operation and Maintenance Guide Volume III, Boilers, states that the "frequency of cleaning cannot be laid down in any precise manner; it depends on the percentage of impurities in the fuel, the quality of combustion, on the effectiveness of fuel additives, etc. It is recommended that washes be spaced out as much as possible, being carried out at the earliest after 3000 hours of operation, but perhaps occurring only after 6000 hours, provided that intermediate inspections of the elements prove satisfactory."

[48] Blue-ram is a high temperature plastic (moldable) refractory material. Unlike "castable" refractory, which is a cement-like product that is mixed with water before use, plastic refractory is sold pre-mixed, and ready to use as shipped.

[49] NTSB interview of boiler 2nd engineer on May 27, 2003. Cleaning was prompted by refractory falling down and blocking the flame. At that time a decision was made to go ahead do the full 3000 hour cleaning, even though it was not due for more that 1000 hours.

[50] The "stoker's log book" for 2003 indicates that boiler no. 23 was taken off-line at 0605 on April 19 and was put on line at 1715 on May 15. The stoker's log book also indicated when boilers had been "skimmed" (surface blown), and tubes soot blown, and when burners had been changed.

[51] Source of information on cleaning work is "chief engineer relieve report, Jan 5, 2003, and "major maintenance & repair work in the engine" log for week 1.

[52] Source of information is "major maintenance and repair work in the engine" log for week 03, 2001.

2nd engineer responsible for boiler maintenance stated "there has been nothing wrong with Boiler 23 for the last four years. No leaking, nothing."[53]

g) Stress concerns. The boiler had historically experienced recurring tube failure problems in addition to drum and header corrosion, pitting and cracking incidents. Even though the problems with cracks in the drums and headers had seemingly abated after 1996 (no documents indicted that cracks had been discovered after 1996), tube failures continued to plague the boilers up until the time of the accident. During various times, several port engineer and chief engineers voiced concerns about the frequent light offs and shutdowns to which the boilers were being subjected as a result of operational schedule requirements imposed by management. The port engineers and chief engineers believed the frequent light-off and shut-downs of the boilers was detrimental to the boiler and causing additional stress to tubes. In a July 2002 email to management, the port engineer at the time of the accident stated:

> The planned re-tubing of the superheaters have had some impact on the consumption; with only 3 boilers in operation, the chief engineer has been uncomfortable in shutting down the boiler on Saturdays, knowing he must light it up again before S. Martens. So 3 boilers have been in line until safe rest-speed to St. Martens has been obtained. Knowing how much stress this lighting up and shutting down has on the boiler, I support this when one boiler is out of service.

In a Jan 2002 email, the same port engineer stated:

> Leaks on the boiler will happen again, and is - once in awhile, not particular abnormal. But with the frequency of leaks we have had lately, particular on boiler 24, it is all reasons for concern, and it has to be addressed. The reason for boiler-tube leaks on the Norway is well known; in and out with the third boiler every single week gives heavy thermal stresses of the boiler-tubes, economizers and brick work. With the present itinerary, delays and/or cancellation of ports must be expected.

In a 1998 email[54], the vessel's previous port engineer stated:

> Since the S/S Norway started the itinerary to St. Maarten, St. John, St. Thomas, Great Stirrup Cay, the ship has been sailing on 2-3 boilers. This operation is causing a lot of stress to the boilers, because we are forced to shut them down frequently. After a few years of operating in this condition, and being the boiler shut down for more than 100 times, and light off every year, we can see that the steel is getting brittle and the reoccurrence of tube failures. If we want to continue the safe operations of the vessel with no mechanical interruptions, the retubing of all 4 boilers should be done soonest.
> During the last few years, we experienced numerous boiler tube failures, which caused shutting down the boilers for repairs. We must realize that we have reached a point, where the operations of the vessel is not safe. Also we should take in consideration that the interior of the boilers are worn out due to sulfur-dioxide corrosion.

However, in an August 1997 report[55], a boiler contractor submitted a proposal to retube the boilers stated that the boilers could be returned to reliable operation simply by retubing:

> Although these boilers are around 40 years old and are currently suffering from on going tube failures there is no report of the main components – i.e. headers or drums – having any Conditions of Class put on them. It is known that various defects have been noted in and attend to in the past, but we would not suggest that this precludes these components from many more useful years work, once the deteriorating tubes have been addressed. To replace the boiler with new plant in its entirety will obviously solve the current leaking tube problems, but is the associated vast expense necessary, and can it be paid back during the expected life of the ship? Retubing the boilers by a professional specialist with ISO 9002 accreditation will return the plant to a good status of reliability, and any unknown defects discovered during the retubing operation can be dealt with at the time by

[53] NTSB interview of boiler second engineer on May 27, 2003.
[54] Mar 16, 1998 from port engineer to NCL management (ship operations vice president)
[55] 1997 August 31 Report by Harris Pye Marine, LTD, to NCL on the feasibility of retubing all 4 boilers at sea or during retrofit.

experienced boiler repair engineers using the appropriately skilled and qualified tradesmen – at a small fraction of the cost of replacement!

h) Water testing. The water in the boilers was tested once per day by a second engineer specifically assigned to that duty.[56] The second engineer maintained a record of the test results and chemicals treatments in a log book kept on the vessel. The operator had a contract with a chemical company (Drew Marine Division of Ashland Chemical), to supply test and treatment chemicals for the boiler water. The stated purpose of the water testing routine was "to ensure that the proper residuals of treatment chemicals are maintained at all times and to detect the presence of contaminants in the water that may be injurious to the boiler, diesel engine, and other equipment."[57] The primary goal of the chemical treatment program was to minimize scale formation and corrosion of the boiler system. In order to achieve these objectives, the boiler water was treated and tested to control phosphate levels, alkalinity (P and T), Ph levels, chloride levels, dissolved solids, and oxygen levels (as indicated by the amount of oxygen scavenger present in the water). Adjustments to boiler water chemistry is accomplished by the addition of Drew Marine chemicals (such as phosphates, sodium hydroxide, and hydrazine) to the boiler water, or by bottom or surface blowing (skimming) of the boiler water.[58] In addition to the treatment and test chemicals, the contract included technical services. A service engineer from Drew visited the vessel about once per month while the vessel was in the port in order to review the record of tests done by the second engineer, to perform independent tests of the boiler water, and to provide training to members of the crew on boiler water testing procedures. A service report would be written by the service engineer that documented the results of his visit to the vessel, and copy of this service report was sent to the port engineer and the chief engineer. A review of of available historical service reports indicated that the service engineer did frequently comment about deviations from standard levels of chemicals and the need to maintain the levels within prescribed limits, but did not indicate that NCL's admistration of the chemical program was erroneous, including in times of boiler layup. As stated above, the purpose of the chemical treatment program was to minimize scaling, sludge, and corrosion on the internal surfaces of the drums and tubes, however, according to statements by representative of the Drew Marine office in Miami, the service engineers did not examine the interior of the boilers to evaluate the effectiveness of the water treatment program.[59] Instead, they relied primarily on their review of tests done by the crew and their own monthly tests to evaluate the effectiveness of the water treatment program. In addition, the service engineers stated that they were not aware of historical problems with tube failures and drum and header cracking problems. The service engineers were not closely monitoring the lay-up status of idle boilers, and the water test and treatment logs maintained by the crew did not indicate whether the boilers were in a dry or a wet lay-up status. The water test and treatment logs did not indicate the levels of hydrazine present in any boiler that was not in operation.

7) Operation

a) Light-off. The boiler light off procedures used by the crew closely matched the recommendation of the boiler manufacturer[60] and industry norms. The procedures to be followed by the crew were posted in the boiler room by the chief engineer. Generally, according to witnesses from the crew, the steam pressure would be raised slowly using intermittent firing of a single burner. Steam pressure was raised over a period of several hours. A watch second engineer, who had been aboard the *Norway* since 1999, described the procedure as follows:

[56] June 03, 2003, NTSB interview of second engineer responsible for testing of water indicated that the second engineer tested boiler water once per day on the midnight to 0400 watch.
[57] Drew Marine *Shipboard Water Treatment Manual*.
[58] Drew Marine *Shipboard Water Treatment Manual*.
[59] NTSB interview of Drew Marine service engineers, Nov 20, 2003.
[60] Liner "France Propulsion Machinery Operation and Maintenance Guide, Volume III, Boilers, Section III Operation, Part A – Starting Up. Interval firing is specified until 8 kg/cm^2, after which continuous firing is allowed. The manual states that "about 3 hours are required to reach a pressure of 60 kg/cm^2. It is nevertheless advisable not to accelerate the procedure, and to allow the temperature to rise gradually.":

> We used to start heating the boiler when we are in St. Thomas, and we start about 8:00 in the morning, something like that, and the stoker open for -- take one of the pump, fuel pump at high speed and the stoker open for fuel and the steam to the boilers, and we start the process for eight hours, eight to nine hours, till we have full pressure. We do it very slowly. So, I may be lighting every -- I don't -- every five minutes and five minutes, switch on the burner for five -- five minutes and switch off 10 minutes the first hours. Normally, we should -- we have 60 bar on the boilers about 6:00 in the evening, normally.[61]

b) Shutdown. The procedures for shutting down a boiler are specified in the original boiler operation and maintenance manual. They procedures state that "when the boiler has cooled down, about 48 hours after extinction, fill the superheater." The procedures for shutting down a boiler were also posted in the boiler room for used by the crew.[62] The posted procedures did not specify a time period for raising steam or for cooling down a boiler. The shutdown procedures used by the crew was described by several witnesses from the crew. Some inconsistence existed between the statements of several of the crewmembers, but according to the second engineer responsible for boilers the procedure he used was as follows:

> The first thing we do is change the fuel to manual, then I switch off the Burner Number 1, then I wait a few minutes and I switch off Burner Number 3, then I decrease the fuel flow. Then I reduce the fuel flow to about 1.5 ton an hour, then I switch off Burner Number 4, and I reduce the fuel flow to about one ton an hour. After a few minutes, I switch off Burner Number 2 which leave the boiler with only one burner left. Then I open starting line that is steam up to the stack [superheater vent]. Then we shut off the last burner and we start to close the valves. And the air flow will be reduced to about 25 percent. It's also the drains to the oil pan, the cork drum, the superheater, superheater steam drain from the Cockburn, and from the A-42, the main shut-off one. Then during period of six to eight hours, the pressure will go down slowly until it reach zero.[63]

According to the second engineer, the forced draft fan is left running during the cool down period "is to have the whole boiler cool down at this same rate, same temperature. If you stop the fan and stop the air, one part may be very hot, the other a little bit colder, but you keep it evenly with the fan running. But just to say it's an easier way. You are transporting the heat out of the boiler with the fan." And the drains were left open to "keep circulating the steam inside, so the tubes won't be damaged."

According to another second engineer, the procedure he used was as follows:[64]

> when we're reducing the main engines and get about on the fuel flow about 2 ton an hour, we start to take out one-by-one of these burners, and we take the first burner out and we have everything out, I do that. I do that. I have all the fueling, and we reduce that a little bit step-by-step and then we take up Burner Number 3, start Burner Number 3, fueling. So, I do the fuel and then take this Burner Number 4 off. There may be 10 minutes, 7 to 10 minutes, take it off, and when we -- when we have one burner on, have only one fan, just stop the other fans, only one fan running, run at least two fans on each boiler, and this stoker start across to the boiler and he knows when it should be closed and then I take off the last burner and turn off the last fan to about 20 [percent], something to that effect, 15 to 20, and we open the drain for the superheater and the desuperheater. The stoker opens that and closes the spray water and this superheated steam …

When this same second engineer was asked how long it would take to reduce the pressure on the boiler from 60 bars to 0 bar, the engineer was uncertain, but estimated 1 to 2 hours. He also stated that the force draft fans are left running during the cool-down period. He also stated that he would give the boiler a 20 minute bottom blow – "Used to open the boiler about 20 minutes, so it loses a

---

[61] Safety Board interview of 12 to 4 second engineer, Jun 03, 2003.
[62] Documents were titled "Procedure for Closing a Boiler" Procedure for Lighting Up a Boiler" specified the order of steps to be followed but did not specify a time period over which the procedures were to be accomplished.
[63] Safety Board interview of boiler second engineer, Jun 06, 2003.
[64] Safety Board interview of watch 12 to 4 second engineer on Jun 3, 2004.

lot of pressure and, of course, the first 20 bar goes very fast. The second engineer elaborated by saying:

> Q: And do you direct the bottom blow? Do you always bottom blow whenever --
> A: Should always bottom blow. That's the process.
> Q: And you get what, a 20-minute bottom blow?
> A: 20 minutes should be.
> Q: And then, you're filled --
> A: Refilled. Refilled the heater. We have then the filled water around this. It's opened like a crack or something. We fill the water till we finish the bottom blow and everything, and the stoker come -- I leave the boiler and the stoker take over. I keep an eye on the water in the other room to the boilers that cool down and that pressure is up.[65]

c) Chart recorders. As mentioned in the boiler description section of this report, the boiler monitoring system had several strip chart recorders[66] that recorded various boiler operating parameters, such as drum level, superheat temperature and steam pressure. The chart recorder that recorded the boiler pressure indicated the pressure of the boiler over time, and could be used to estimate the time warm up and cool down times during light-off and shut down evolutions. In the charts shown here, the elapsed time is on the horizontal axis and the value of the measured parameter is on the vertical axis. Each vertical line on the time scale was thirty minutes, and each hour was marked by a number, although the numbers did not necessarily correspond to the actual time of the recording. For example, the elapsed time between 16 and 17 was 1 hour, but 16 did not represent 1600 hours. The chart recorders paper advance rate was tested and verified after the accident. Examination of several charts revealed similar pressure-rise and pressure-fall profiles during light-off and shut down evolutions. Light off profiles were consistent with intermittent firing of the boiler, and resembled a saw-tooth shaped curve. Shutdown profiles indicated a steadily decreasing curve, with the slope of the curve indicative of the rate of pressure fall with respect to time. The charts generally revealed that during light-off, pressure on the boilers was raised from zero to full pressure in about four hours; and during shutdown, pressure was reduced from full pressure to zero pressure in about three hours.

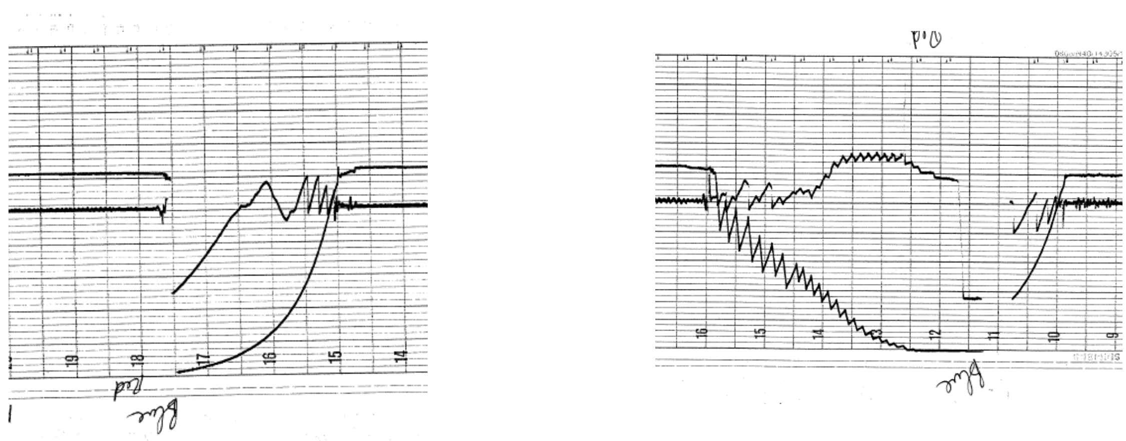


Figure 4 - Pressure-Time Strip Charts – cool down (left chart) and warm up (right chart)

[65] Review of the "Stoker's Log" for 2003 indicated that when boiler no. 23 was secured on April 19, 2003, it was given a 15-minute bottom blow. Other entries in the stokers log indicate that on several occasions, boilers were given a 15 or 20-minute bottom blow after being secured.

[66] A strip chart recorder consists of a roll of paper that is passed linearly beneath one or more ink pens. As the signal representing the monitored parameter changes the pens deflect producing the resultant chart. If the signal was constant, a straight horizontal line is drawn on the chart. Strip chart recorders are well suited for recording of continuous processes, such the boiler steam pressure. The crew had maintained onboard several years of recorded strip chart data for the boilers.

d) Lay-up. The vessel usually steamed with either 2 or 3 boilers in operation. Three boilers were used when the schedule required higher speeds, and only 2 boilers would be operated when the schedule allowed for reduced operating speeds at sea. Although, recently, the ship had generally kept three boilers continuously on line during the summertime. In an interview, the chief engineer described the boiler operational situation as follows:[67]

> We didn't cut out boilers, because it happened before we could run on two boilers, but because of the, then we had to take out one boiler when we arrived into the Island and we had to light up a boiler when we departure Miami and that is too much stress for the boiler. And that is, we have found out that you are not gaining anything. And so we keep in the summer time, we keep the three boiler running. And even in some cases, there is nothing left to go from St. Thomas to the private island, with three boiler, only when we are leaving on schedule. If we are a half hour late from St. Thomas, we can't even make it, and if we are three quarter of an hour, half hour late to the island. So, we are running over at this time, we have the three boilers".

In addition to short duration lay-up of a boiler that was in a standby condition, normally one of the four boilers was in longer term of idleness, often under undergoing repair or maintenance. This operational status made the boiler a good candidate for long term lay-up preservation procedures. The ships water testing and treatment logs did not indicate what type of lay-up procedures, if any, that were implemented on boilers that were not in a steaming condition.

The original boiler plant operating manual from the French time recommended that if the boiler was to be "shut down for a prolonged period (5 days or more), completely fill the upper drums up to the air released, injecting hydrazine."[68]

According to guidance provided by the company that supplied the boiler chemicals, boilers that were off-line for "extended periods of time" were to be protected against oxygen gas corrosion through the use of high concentrations of an oxygen scavenging chemical.[69] The guidance also states that a wet lay-up (as opposed to dry lay-up) be used for "all but very extended lay-up periods." The terms "extended periods" and "very extended lay-up periods" were not specifically defined in terms of days or weeks. The *Norway*'s boilers were subjected to cyclical operation during which boilers were placed in an idle condition of days or weeks at a time, and no indication was found that the boilers were protected against oxygen corrosion as recommended by the chemical supply company.

8) Boiler inspections by classification society

a) Surveys. Bureau Veritas (BV), a French classification society, had been the vessel's classification society since it was constructed. According to BV, American Bureau of Shipping (ABS) also surveyed the vessel during its construction and the first years of operation.

The boilers on the vessel were submitted to occasional, annual, and complete surveys. Occasional surveys were done on an unscheduled basis in order to inspect a particular aspect of the boilers, such as satisfactory completion of a significant repair or to bring a significant condition of the boiler to the attention of the class society. The annual boiler survey was done approximately every 12 months, and the internal and external, or complete survey,[70] was done approximately every 2-1/2 years. Many of the surveys done on the *Norway*'s boilers were done in the port of Miami by surveyors assigned to the Port Everglades office of the classification society, and other surveys were done at European ports during

[67] Safety Board interview of chief engineer, May 26 , 2003.
[68] Liner "France Propulsion Machinery Operation and Maintenance Guide, Volume III, Boilers.
[69] Drew Marine Shipboard Water Treatment Manual, 4th Edition, page 24, discusses lay-up of idle boilers. The manual recommended that the hydrazine levels be increased from the normal .015-.02 ppm to 150 to 200 ppm during periods of wet lay-up.
[70] According to a classification society witness interviewed on Jun 06, 2003, the "complete survey" is now referred to as an "internal and external survey."

shipyard overhaul periods, such as Bremerhaven or Southhampton, by classification society surveys in those regions.

b) Annual or external surveys. The classification society inspected each of the boilers on an annual basis. The last annual survey of the boilers was done May 11 through 18, 2003.[71] The annual survey consisted a review of the operating logs and a general check of the external areas of the boiler. According to the classification society surveyor who did the last two annual surveys and who had been associated with the *Norway* since 2001, the annual survey was "only a visual examination on the outside of the boilers," such as a checks "for oil leaks, for steam leaks, for -- I mean, the installation or, you know, but, the things you would normally look for on the outside." He also stated that he did not see any irregularities with any of the boilers during the last annual inspection and he did not make any discrepancy notations on the inspection record.[72]

c) Complete or "internal and external" surveys. The last complete survey on boiler 23 was done on July 21, 2002. During that inspection, a hydro test of the boiler was carried out with a test pressure of 70 bar because the secondary superheater tubes had just been renewed. The class surveyor who performed the survey described the normal survey procedure as "you inspect the tubing, you inspect the fire box, you inspect the drums, as far as you can get in and check them, because they are very narrow. And, of course, all the tubing, the combustion chamber, and whatever." In addition, a test of the control system is done to verify that "the functions are done, what is required for."

According to guidance provided to surveyors by the classification society,[73] the complete survey includes:

> A complete boiler survey allows to check out if any build-up of deposits has taken place, and deformations or wastage of platework, piping or any of the various parts, which may compromise the safe working order of the unit. The survey includes research as to cause of any anomalies found and also their correction. A complete survey means a full internal and external examination of all parts of the boiler and accessories such as superheater, economiser, air-heater internal organs and all mountings. This examination may lead the Surveyor to require thickness gaugings of plate or tubes that appear to be wasted and eventually to a lower assigned working pressure, if calculations prove this necessary.

BV guidance for internal inspection of the upper drum directs the surveyor to check for check for pits in the area of the bellmouths of expanded tubes, and if serious, then a tube should be removed to verify its thickness. In addition, surveyors are directed to look for cracks between tube holes in the drum, as "these will probably be hair-line and are extremely dangerous, but fortunately rare."

Regarding inspection of the lower drum, the classification society guidance states:

> An internal inspection will not usually show much but any signs of pitting in the upper drum or tubes should be followed up by a further examination of the tubes via the lower drum. Manhole doors, their landings, joints and dogs should be carefully checked.

No specific guidance was provided regarding the inspection of waterwall headers. However, the guidance states that waterwall tubes "are open to the same defects and causes as screen tubes, but are more sensitive to poor circulation. A stoppage in the feed-water supply even of very short duration can cause heavy deformation particularly in the roof tubes."

According to the BV guidance, hydraulic tests are required when:

> Significant repairs have been carried out, such as renewal of plate in combustion chambers or renewal of furnaces in Scotch boilers or repairs involving welding or major renewals of tubes; the

[71] The classification society surveyor was interviewed by the Safety Board on May 28, 2003. He stated that the boiler surveys were done as part of the annual passenger ship safety survey, during which all of the ships equipment was surveyed.

[72] Safety Board interview of classification society surveyor conducted on May 28, 2003.

[73] Bureau Veritas TNS 05 – Boilers Complete Surveys, provides instructions for the performance of the boilers complete surveys as required by the Society's Rules.

boiler has not been fully surveyed internally; the surveyor has doubts about the general condition of the boiler.

When questioned about his knowledge of reoccurring historical problems with the boiler, the present class surveyor stated[74]:

Q: Regarding the boilers generally, are there any abnormalities in the past, any of the boilers, that seem to be a recurring problems or in the past surveys?
A: Not to my knowledge.

Examination of the inspection records, of course, revealed a long history of problems with corrosion, cracks, and pits. When asked whether the class society would continue to monitor historical problems in a particular piece of equipment, a senior representative of the society stated that when a permanent repair was completed, no monitoring of the repair was maintained. During a Safety Board interview he discussed the topic as follows:

Q: When a class society becomes aware of an issue or a problem, how do they track that problem throughout the history of the vessel?

A When there's a problem, in general there are two, I would say three possibilities. First, wait and see. If there is a problem that doesn't seem too serious, but we want to monitor it, so we would enter a recommendation or a note in the certificate saying this we want to reinspect every year or every two years to monitor the evolution of the problem. It can be a boiler, it can be corrosion in a tank, it can be anything on the ship.

The second possibility, provisional repairs are made immediately or maybe any time. Provisional repairs means it's not permanent repairs. Is there is a provisional repair, there will be at the same time a note or recommendation saying provisional repairs to be definitive repairs to be provided by such date. Could be the next technical stop, the next dry dock, you know.

The third step, definitive repairs. Definitive repairs are done with specialists where either the equipment is replaced or it is repaired in such a way that it is considered as final. It is tested after repairs. If specific competency, such as (inaudible) are requested, specialists will come to attend and check the repairs and once it is declared final, it is final. We don't track it anymore.

Q You don't track it anymore?
A No. We will track it if the specialist doing the repairs say we recommend that this being reassessed every two years, five years, ten years. But if the repairs is considered as good enough by the specialist and by the controls which have been done on the repairs, there is no reason to put a recommendation to be reinspected five years later.

When questioned about his inspection of the internal areas of the drums and headers the surveyor at the time of the accident stated:[75]

Q Do you normally have the steam drum internals removed or is that not done?
A The steam drum is always opened up, but I have not been in the steam drum because the manhole is a little bit too small.
Q On the upper steam drum?
A Yeah.
Q What about your inspection of the lower drum, the water wall drum? Excuse me, the water drum. Is that manhole accessible to you?
A No. You can look in, but I can't get in.
Q What about the smaller drum or the header, the water wall header? Is that manhole accessible? Can you get into there?
A No, it's too small. But you can look in.
Q You can look in?
A Yes. You can look for corrosion or whatever, but it's limited.

[74] Safety Board interview of classification society surveyor, May 28, 2003.
[75] Safety Board interview of classification society surveyor, Jun 06, 2003.

Q So you normally do not go into the lower drums?
A No. It's not required.
Q Not required?
A No.

The previous surveyor from the Port Everglades BV office was assigned to the *Norway* from 1991 until 2001. He stated that he was not aware of any welding repairs that had been done on the boilers during his oversight of the *Norway*. In an interview he stated:[76]

Q: During the time you were doing the surveys aboard the Norway, do you recall any repairs being done on the -- on the drums or the headers on any of the boilers? Any type of welding repairs?
A: No.
Q: And is that something that you're fairly certain of or it's just your recollection? Would you have to refer to any documents to -- to verify that or not?
A: It's my recollection, but also, the records of the ship are quite -- you know, for instance, when it went over to Europe for repairs, we -- we had all the -- the reports came to our office. So, I'm -- I'm fairly -- I'm -- I'm really quite sure, but I could be wrong, of course, but I believe it was no -- no -- no repairs done to the drums.

On further questioning during the same interview, this surveyor stated:

Q: Since '91 or '92, since you've been working on the Norway, have you become aware of any problems with cracking, abnormal cracking or pitting on the drums or any major components of the boiler?
A: No.
Q: Since -- during that time, have you become aware of any maybe less significant cracking that maybe was identified but was thought to be not significant enough to pursue?
A: No.
Q: Are you aware of or have you heard of any cracking that had been ground down and rewelded and just monitored since you've been affiliated with the Norway surveying?
A: On the boilers?
Q: Correct.
A: No.

The previous BV surveyor also stated that he had entered the steam and water drums of the boilers, but had not entered the waterwall header of the drums, he had only sighted the interior of the header from the outside. He further stated that the BV guidelines did not require surveyors to enter into the water drum and waterwall header, entry was required only into the steam drum.

The BV surveyor who performed boiler surveys during the 1980s and up to 1991 reported did enter into the drums and headers during inspections. When questioned on this topic, the previous port engineer of the *Norway* stated:

Q: Would -- in your opinion, would you say that a good examination of the water headers would entail someone actually getting inside or could they see -- examine the drum in entirety by putting their head inside with a flashlight?
A: No. You have to go in.
Q: You have to go inside?
A: And it's a very, very cramped space. Not everybody can get in there.
Q: Would -- okay. Did you ever see in your time anybody entering -- actually getting into them?
A: I've been in there myself. Not today, but 15 years ago, I was in there.
Q: You went in there?
A: Yeah.
Q: So, you actually physically went in?
A: Yeah.
Q: Okay. Did you ever see anybody else?

[76] Safety Board interview of previous classification society surveyor of *Norway* boilers, conducted on Jun 06, 2003.

A: Yeah. I seen people in there. Oh, yeah.
Q: Any -- any Veritas people?
A: Yes. I seen them.
Q: They have been inside?
A: Oh, yeah.
Q: Okay.
A: Yeah. All the -- Mr. Moore from Bureau Veritas, he was 75 years old and he was in there.
Q: Okay. Good. So, you said it's obviously better to get inside there and examine --
A: You have to because you cannot see what's inside, no.
Q: You said -- was that -- okay. Okay. Fine.
A: It's almost impossible to -- to see anything if you don't get into it.

Bureau Veritas records showed that in a September 5, 1996 memo, BV London asked for information on "history of of any problems with the boilers and major repair history so that we are better guided for our surveys" In response, in a September 29, 1996 memo BV Miami advises BV London " A particular attention has to be paid to the Main and Auxiliary Boilers. Some cracks were found since 1987 on the various drums of the MB as indicated hereafter. Particular attention to be paid to monitor these details. We will copy information from BVC file asap." Attached to the Sep 29, 1996 memo was a copy of a Lloyd Werft Bremerhaven report discussing cracks in boiler 21. Reference is made to a Sept 15 & 18, 1987 Vetco Services report of crack testing. Report also describes the welding repair procedure to be used.

9) Boiler Inspections by Flag State.

a) The vessel sailed under the French flag from the time of its building in 1961 until 1979 when it was sold to its present owners. In 1979, Kloster Cruises purchased the *S/S France*, renamed it the *S/S Norway*, and registered the vessel in Norway. In response to a request for copies of documents regarding boiler inspections conducted by Norwegian flag state authorities, the following response was received by the Safety Board:[77]

> Having examined the existing documentation at *S/S Norway*, the Norwegian Maritime Directorate regrets to inform you that we do not possess any documentation containing inspection records of the main boilers.

b) In 1987, the operator reflagged the *Norway* to the Bahamas flag.[78] According to information received by the Safety Board, Bahamas flag state authorities did not conduct boiler inspections, but rather relied on inspections conducted by classification societies. In response to a request for information regarding the nature of boiler inspections conducted by flag state authorities, the following response was received from a representative of the Bahamas Maritime Authority (BMA):[79]

> … we do not carry out or oversee boiler surveys, as the work is carried out entirely by the Classification Society. We are dependent upon them to notify us of any problems which require our attention and to that end we have access to the Classification Society records via internet.
>
> It is a Condition of Registry that the vessel remains "in Class" i.e. satisfies all Classification Society requirements. This gives us some assurance of satisfactory technical and structural condition of the vessel.
>
> Our agreement with the Classification Societies (we have selected only eight of the IACS societies) allows them to carry out statutory surveys on behalf of the Bahamas. It has to be that way as the

[77] E-mail from Norwegian Maritime Directorate dated Jan 21, 2004
[78] Reflagging of vessels is often done to for purposes of reducing operating costs or avoiding government regulations. However, all ships under Bahamas flag are required to adhere to all international conventions (such as SOLAS, MARPOL, ILLC, STCW and ILO), and BV surveyed the *Norway* on behalf of the Bahamas for compliance with such conventions.
[79] E-mail from Bahamas Maritime Authority dated Sep 17, 2003,

Class Societies are the only appropriate bodies with a worldwide network of offices and surveyors able to carry out this work. Similarly our recognized organizations for the purposes of administering the ISM Code are the same eight Classification Societies. Our annual Bahamas inspections also serve as a check on the work carried out by the Classification Societies on our behalf.

…the information contained within the Bahamas annual inspection report is of a general nature, designed to give us an overview of the vessel condition and onboard management. Therefore we would not expect to see any report which specifically contains a reference to boilers, unless the inspector noted (for instance) an overdue condition of class or obvious defect. No such references are seen.

10) Wreckage

According to the operator, the damage to the *Norway* as a result of the accident was between $20 and $23 million. On June 27, 2003, the vessel left Miami and was towed to a shipyard in Germany. As of the date of this report, a decision regarding its final disposition had not been made by the vessel operator. Consideration had been given to either installing new boilers or to installing diesel engines, but doubt remains if the vessel will ever be put back into operation.

The major damage to the vessel was primarily limited to the boiler room in the vicinity of boiler no. 23. A large section of the waterwall header was liberated, and was found on the deck next to the boiler. Extensive damage was done to the starboard aft side the boiler room, outboard of the boiler. Other less significant damage extended into the adjacent compartments, and consisted primarily of the deposition of lightweight material resembling fibrous insulation in the path of the gas flow away from the explosion site. Some damage was done to the crew berthing and mess areas on the starboard side of B and C decks (such as displaced bulkheads and doors), and several crewmembers were killed and injured in these outside spaces. No evidence of fire was found either in the engine spaces or the crew accommodation spaces. See Appendix A for the detailed damage report.

11) Tests and Research

a) **Boiler safety valve check**. During the on scene portion of the investigation, the four safety valves were tested in order to determine if they were functioning properly at the time of the accident. Appendix B contains the details of the tests conducted.

b) **Burner management and safety system test**. During the on scene portion of the investigation the burner management system was tested to verify that it was operating properly before the accident. Because of the extent of the damage to several components of the system, a normal system test procedure could not be carried out. Nevertheless, although full safety line check test could not be completed, a test of the undamaged portions of the safety system was completed by simulating boiler inputs from sensors and operating devices in the boiler room and the results indicated that the safety system was working as intended. The test was conducted by a representative of the system manufacturer, who was also a party to the investigation. Refer to Appendix C for details of the system test.

c) **Fuel oil tests**. The fuel oil in the storage tanks at the time of the accident was sampled and submitted to a fuel testing laboratory for analysis. The fuel oil in use at the time of the accident was 380 cSt viscosity grade. Flash point tests done on samples of fuel from the tanks on in service and from the fuel oil piping at MB # 23 indicated that the flashpoint was in excess of 200 deg F.

d) **Burner front hardware tests**. The burners, retractable igniters, and fuel valves from the front of boiler no. 23 were tested for proper operation. The tests were arranged by the operator and witnessed by a representative of the USCG. The tests indicated, to the extent possible, that the boiler front hardware was operating properly. [The Safety Board is awaiting delivery of the test report from the USCG.]

e) **Non-Destructive Testing (NDT) of boilers**. Following the accident, the operator contracted with another classification society, DNV, to evaluate the condition of the drums and headers of the remaining three boilers not involved in the accident. The testing was done by DNV's metallurgical laboratories in Norway by a specialist engineer knowledgeable with such tests. The test performed were plastic replica testing, hardness testing, and magnetic particle inspection (MPI). The tests found significant pitting and corrosion that needed to be removed in order to conduct NDT for cracks. In addition, the MPI testing found cracks that required repair before the boilers could be returned to service. And finally, the plastic replica examination of the drums and headers microstructure found "significant material degeneration due to carbide coarsening and the formation of creep pores," and concluded that the "drums are not suitable for further safe operation."

In addition, the Safety Board contracted with a firm to perform NDT in the other three boilers not involved in the accident. The testing was done on June 23-26, 2003, and according to report submitted by the contractor, "Fluorescent Magnetic Particle examination located cracks in the welds of headers 21, 22, & 24, and in the welds of water drums 22 & 24. No cracking was observed in water drum 21 or steam drum 22." Ultrasonic testing was done to measure the depth of the cracks found. The full report of the testing done is part of a separate factual report prepared by the metallurgical group chairman.

f) **Metallurgical Testing of waterwall header**.. During the on scene portion of the investigation several coupons were removed from different locations on the waterwall header and the section liberated from the waterwall header. These coupons were later subjected to metallurgical examination in the NTSB materials laboratory. The metallurgical testing found evidence of fatigue cracks at the fracture surfaces. The results of these tests are documented in a separate factual report prepared by the metallurgical group chairman.

g) **Boiler Operation Guidance**

i) The shutdown recommendations of a boiler of similar design, capacity, and pressure was used as a comparison to the boilers on the *Norway*. The technical manual states "in order to prevent possible damage to the steam drum and pressure part joints from thermal strains, it is desirable that the pressure be reduced (from line pressure to 50 psig) in not less than three (3) hours."[80]

h) **USCG Alternate Compliance Program (ACP).** The ACP allows certain authorized classification societies to perform inspections of U.S. flag vessels on behalf of the USCG. According to the USCG ACP website,[81] the ACP is "intended to reduce the regulatory burden on the maritime industry while maintaining existing levels of safety and providing increased flexibility in the construction and operation of U.S. flag vessels. In this voluntary program, Classification Society Rules, International Conventions, and a U.S. Supplement provide an equivalent alternative to the CFR. Compliance with this equivalent alternative standard is administered through traditional survey and inspection conducted by authorized classification society surveyors. A Certificate of Inspection (COI) is issued by the Coast Guard to a vessel based upon these classification society reports." The U.S. Supplement is a separate document that identifies "all regulations applicable for issuance of a Certificate of Inspection (COI) which are not, in the opinion of the Commandant, adequately established by either the class rules of that classification society or applicable international regulations."[82]

i) **Inspection Guidance by Other Agencies**. For purposes of comparison to guidance provided by Bureau Veritas to its surveyors, the following is a summary of the relevant portions of the guidelines given by other inspection agencies regarding the inspection of boilers. The ABS, LR and DNV guidance information is taken from internal company documents that are not publicly available.

i) **American Bureau of Shipping (ABS).** ABS is a classification society based in the U.S., and it makes the following recommendations for boiler surveys to its surveyors:[83]

[80] Operating manual for the 900 psi boilers aboard the USNS Comfort (T-AH 20).
[81] USCG website with information about the Alternate Compliance program is at http://www.uscg.mil/hq/g-m/mse/acp/acp.htm
[82] 46 CFR Part 8.430
[83] Excerpts from ABS internal document titled "Boiler Survey Notes", undated

The internal fittings in the steam drum shall be removed as necessary to enable entering and examining the drum internally.

Examine the interior of the drum for pitting (usually at the waterline), caustic corrosion or stress fractures, scale and oil deposits, leaking steam separator or desuperheater joints, and for any loose internal fittings. Minor pitting should be left alone but a description and a note shall be made in the report for examination at the next survey.

Water Drums or Mud Drums:

Water drums or mud drums shall be opened and examined for corrosion, pitting, type and extent of deposits, and then washed clean. Normally these are left open until the last in case anything, such as nuts and bolts from the removal of the steam drum internal fittings, happens to fall into the tubes.

Headers and Tubes:

A few hand-hole plates shall be removed from headers, say one at each end, and the inside of the header and any exposed tube ends checked for precipitated solids and scale (particularly at dead-ends or at bends), and for corrosion. Because it is difficult to run a tube cleaner through a bend, deposits may accumulate in such locations. Sighting into the tube openings with a flashlight is the best method of checking this item. Accumulation of magnetic iron oxide in pockets usually indicates uncontrolled corrosion.

For scotch boilers, the following guidance is given:

Fractures:

A Scotch boiler failure is more serious than a watertube boiler failure because of the greater amount of available water to flash into steam. But Scotch boilers will take considerable abuse. Discretion shall be used in ordering extensive repairs, especially on surfaces that are in compression rather than tension. While in a welded watertube boiler, any fracture, no matter how small, calls for immediate action, on a Scotch boiler certain small scattered fractures, if they do not extend inside the line of the rivet holes, show no sign of leakage, and are not grouped together, may be merely noted for examination at the next survey, particularly if the part is in compression.

ii) National Board Inspection Code (NBIC). The National Board of Boiler and Pressure Vessel Inspectors (NBBI)[84] publishes guidance for the inspection of land-based boilers in a document titled *The National Board Inspections Code*. Nearly all states require periodic inspection of steam boilers by inspectors holding a National Board commission. The requirements for earning a commission from the NBBI include experience and training as well as passing a written examination. The National Board Inspection Code contains the following relevant information[85]:

Causes of Deterioration

Deterioration of boilers may be caused by improper or inadequate water treatment, excessive fluctuations in pressure or temperature, or lack of proper maintenance.

Types of Defects

[84] According to its website, "The National Board of Boiler and Pressure Vessel Inspectors was created in 1919 to promote greater safety to life and property through uniformity in the construction, installation, repair, maintenance, and inspection of boilers and pressure vessels. The National Board membership oversees adherence to codes involving the construction and repair of boilers and pressure vessels." In addition, "the National Board Inspection Code is the only standard recognized worldwide for inservice inspection repairs and alterations of boilers and pressure vessels. This American National Standard has been adopted by a number of states and jurisdictions, as well as by federal regulatory agencies including the U.S. Department of Transportation."

[85] Cited sections of NBIC are taken from section "RB-3100 – Inspection of Boilers"

Defects may include bulged or blistered plates, cracks or other defects in welds or heat affected zones, pinhole leaks, improper or inadequate safety devices, wasted or eroded material.

Cracks

a. Cracks may result from flaws existing in material. The design and operating conditions may also cause cracking. Cracking can be caused by fatigue of the metal due to continual flexing and may be accelerated by corrosion. Fire cracks are caused by thermal differential when cooling effect of the water is not adequate to transfer heat from the metal surfaces exposed to the fire. Some cracks result from a combination of all these causes mentioned.

b. Cracks noted in shell plates should be repaired.

   1. Fire cracks that run from the edge of the plate into the rivet holes of girth seams, and
   2. Thermal fatigue cracks determined by engineering evaluation to be self arresting may be left in place.

c. Areas where cracks are most likely to appear should be examined. This include the ligaments between tube holes in watertube boiler drums, between the tube holes on the tube sheet of firetube boilers, form and between rivet holes, at any flange where there may be repeated flexing of the plate during operation and welded pipe and tube connections.

Corrosion

a. Corrosion causes deterioration of the metal surfaces. It can affect large areas or it can be localized in the form of pitting. Isolated, shallow pitting is not considered serious if not active.

b. The most common causes of corrosion in boilers are the presence of free oxygen and dissolved salts in the feedwater. Where active corrosion is found, the Inspector should advise the owner or user to obtain competent advice regarding proper feedwater treatment.

iii) **U.S Coast Guard.** The portion of federal regulations dealing with boiler tests and inspections are contained in Subchapter F of 46 CFR (Part 52). The USCG provides guidance to inspectors of boilers in its *Marine Safety Manual* (MSM).[86] The section of the MSM dealing with inspection of watertube boiler watersides states:

> (i) Examinations of the Waterside. The interior of the steam drum is the best starting point for inspection of the waterside of the boiler. The flanged piping connections of the desuperheater and internal feed lines should be hammer tested; if the tightness of the desuperheater piping is in doubt, it should be hydrostatically tested. The steam drum should be thoroughly cleaned prior to inspection; portions of the drum internal platform should be removed to permit a close examination of the drum interior and the tube ends. Pitting along the waterline, in the bottom of the drum, and in the ends of the riser tubes and generating tubes, is occasionally found. The brackets supporting the dry pipe, internal feed lines, and desuperheater should be examined to ensure that the securing bolts are tight.
>
> (ii) Examination of Tubes. A sufficient number of handhold plates should be removed from the headers of the generating tube bank, superheater, economizer, and waterwall tubes to permit a comprehensive examination of these tubes. In addition to tube inspection, handhold plates should be opened to permit inspection

[86] USCG Marine Safety Manual, Vol. II: Materiel Inspection, Section B: Domestic Inspection Program, Chapter 1: Inspection of Vessels for Certification

of header baffle plates, orifice plates, drain locators, branch lines, inlet/outlets, elbows, thermometer wells, and other locations subject to high stresses or corrosion. Generally, removal of 5 percent of the handhold plates will suffice; however, if internal pitting or an excessive amount of scale is found, it may be necessary to remove all of the handhold plates for a complete examination. Scale deposits exceeding 1/32" in thickness will seriously impair heat transfer, especially in screen tubes and waterwall tubes, and may result in blistered and distorted tubes. Scale should be removed by mechanical means or by chemical washing. Examination of tube interiors is difficult in D-type boilers because the tube bends preclude sighting more than a short distance inside each tube. However, the tubes should be inspected from within the lower drum and, with the aid of a mirror, from the waterwall and superheater headers. The inside surface of the bottom drum should be examined for evidence of pitting; this is occasionally seen in boilers that have been out of service for long periods of time.

In the section of the same chapter of MSM, in the section dealing with pressure vessels,[87] the following guidance is given regarding inspections:

What to look for.

All internal surfaces should be carefully examined for evidence of fractures or indications of deterioration. The heat affected zone adjacent to all welds should be given special attention. All welded joints, as well as all nozzle connections and similar openings, should be thoroughly examined.

Two critical factors are illumination and accessibility. There must be sufficient light to allow a thorough examination of all welds and plate surfaces. Bright illumination is necessary for all visual examinations. If access to the internal areas is limited to small "inspection openings," a flashlight beam directed through such openings may not provide sufficient illumination for examination. When this occurs, other types of lighting can be used, e.g., flexible lights, borescopes, etc. If the P/V is equipped with a manhole the inspector should be able to get inside, close enough to scrutinize all internal areas. The P/V must be clean enough to allow a thorough examination of all surfaces; the presence of water, grit, or other matter inhibits examination. If the inspector cannot satisfactorily see the area of concern with a bright light directed at the area being examined, a "satisfactory" internal examination cannot be conducted and the vessel should be tested by means acceptable to the OCMI to satisfy the periodic inspection requirement.

Inspection intervals. According to Coast Guard regulations,[88] propulsion boilers are to be inspected at intervals in accordance with the following table:

INSPECTION INTERVALS FOR BOILERS

	Watertube Boilers
Hydro Test:	
• Passenger Vessel	5
• Other Vessel	2.5
Fireside Inspection	2.5
Waterside Inspection	COI
Boiler Safety-Valve Test	5
Valves Inspection	10

[87] Distinct regulations cover boilers and pressure vessels, they are not synonymous terms. A boiler generates steam while a pressure vessel does not.
[88] 46 CFR 61.05

Studs and Bolts Inspection	10
Steam Gauge Test	COI
Fusible Plug Inspection	----------

Hydrostatic test requirements. According to the MSM and Coast Guard regulations:

"Hydrostatic tests must be applied to all watertube boilers quadrenially (annually in the case of passenger vessels). Excepting passenger vessels, OCMIs are authorized to extend the hydrostatic testing interval for one year (12 months), to a period not to exceed five years (60 months) since the last hydrostatic test. In the case of passenger vessels, the hydrostatic test interval may be extended up to a period not to exceed 30 months since the last test, provided that no less than two hydrostatic tests are conducted within any five year period. OCMIs may extend fireside and waterside examination intervals for watertube boilers, including economizers, auxiliary boilers, low pressure heating boilers, and unfired steam boilers to a period not to exceed 30 months since the last examination, provided that no less than two such examinations are conducted in any five year period. It is anticipated that the aforestated authorizations shall be exercised primarily to permit the test and examination interval to coincide with the vessel's drydocking or similar out of service availability period. Hydrostatic pressure tests are applied annually to passenger vessel boilers, and at 5-year intervals to the boilers of other vessels. Following repairs and at the conclusion of inspections, watertube boilers should always be hydrostatically tested to a minimum of 1.25 MAWP (if substantial modifications or repairs have been made, to 1.5 MAWP)."

iv) **Det Norske Veritas (DNV).** The Norwegian classification society, DNV, issued guidance to its surveyors on the conduct of boiler inspections[89] and the relevant excerpts are as follows:

Due to the potential risk a boiler represents and the consequences any damage may have, it is of the utmost importance that the survey is performed in a conscientious manner.

Proper cleaning of the boiler prior to the survey is essential for the quality of the survey as fatal damages may be hidden under soot or scales. The matter of a not properly cleaned boiler should be taken up with the Master of the ship in order to have this problem solved, but the surveyor should not accept to undertake survey of a clearly not properly cleaned boiler.

Unfortunately, too many auxiliary boiler designs are such that it is difficult to carry out visual internal examination. If proper internal examination is not possible, the surveyor may resort to ultrasonic and/or hydraulic testing to determine whether the boiler is in a safe working condition.

Experience has shown that auxiliary boiler of 10 to 15 years of age are especially exposed to fatigue damage, thus testing as indicated above should be seriously considered by the surveyor if proper internal examination is not possible.

Scope of Survey – water and steam drums and shell plates with internals

- An internal examination is to be made, look for cracks, corrosion, erosion, pitting and wastage of the shell, on vertical auxiliary boilers, especially attention to the circumferential and longitudinal welding seams. If internals or boiler shell is found wasted, thickness measurements are to be carried out as deemed necessary.

- Any evidence of oil or scale on the waterside surfaces should be removed

[89] Instructions to Surveyors, Boiler Survey – Thermal Oil Heater Survey, No. I-C2.6, dated 2003-10-15.

Headers

- Selected handhole covers are to be removed for examination of internal surfaces and also for deposits, which may obstruct circulation particularly through water-/membrane wall tubes. Leakage at separation wall in headers, may lead to serious overheating of the connecting tubes due to insufficient circulation and erosion inside the header.

Commonly found damages

A large variety of damage to boilers may be experienced as:

- general corrosion, pitting, wastage
- stress corrosion or corrosion fatigue
- erosion, scoring
- cracks, rupture
- buckling, collapse
- overheated, deformation
- leakage

Internal damage is often a result or combination of effects, e.g.;

- unsatisfactory boiler water treatment
- low feed water temperature
- feed water distribution arrangement inside the boiler
- stress concentrations at weld seams and welded connections
- thermal stresses where larger temperature differences occur, e.g. at feed water inlet, superheaters, de-superheaters, furnaces
- overheating, sagging of water walls due to lack of water circulation in the boiler or steam circulation in superheater
- excessive scale or oily deposits
- flame impingement

No repairs carried out

Hydraulic testing should preferably not be carried out. If however, it is not possible to carry out a visual inspection due to, e.g. lack of access (small auxiliary boiler), a test should be carried out with a test pressure not less than max working pressure (as stamped on the marking plate) and not exceeding 1.25 time the working pressure.

An inspection checklist was provide for use by the surveyor. The sections dealing with drum/header inspections stated:

Water/steam drums and shells with internals. Domes/drums: Check for damaged refractory, cracks in way of openings for pipe or valve connections, wastage in way of manhole flanges, internal pitting/corrosion (often caused by deficiencies in the feed water system). If welds are not accessible for internal inspection, ultrasonic test may be necessary to scan from the outside to detect any possible cracks developed due to corrosion on suspected areas. The drum ends to be carefully checked for cracks. Crack are mostly observed in or close to welding seams.

Headers. Selected hand hole covers are to be removed for examination of internal surfaces for deposits which may obstruct circulation, particularly through water wall tubes.

Hydraulic test, boiler. Hydraulic testing, as required for new ships, is always to be carried out when alterations or repairs have been carried out on highly stressed parts. The complete boiler to be leakage tested. Note: At normal SPS (no repairs), hydraulic testing should preferably not be carried out. Only to be carried out if adequate inspection is impossible. If hydraulic test is carried out, name of boiler tested, test pressure and water temperature should be stated in the official report text. Note: If found necessary, the Surveyor may require hydraulic test, thickness measurements and/or crack detection test of any part of the installation.

- After the accident, DNV issued guidance in their quarterly newsletter *Classification News* (2 2004)[90] regarding survey of ageing steam boilers. In part the article in the newsletter stated:

  - Surveyors to perform a general internal examination of both water and fire/gas side, with a special focus on the drums and headers, welding seams for possible cracks, corrosion, pitting and wastage. If conditions described above are found, thickness measurements and/or other non-destructive testing methods will be performed.
  - In the event that the boiler design prohibits a proper visual examination and inspection from the manholes/handholes indicates significant corrosion, pitting and wastage, external insulation must be removed to allow non-destructive testing of critical and affected areas from the outside.
  - For boilers with sliding feet, the marking patterns will be verified in order to confirm whether or not the boiler expands freely during operation.
  - The experience surveyors gain through this increased focus will help DNV in its continuous efforts to improve the Rules and survey procedures.

v) **Lloyds Register of Shipping (LR).** The British classification society Lloyds Register of Shipping issued boiler inspection guidance to its surveyors,[91] and the relevant portions are as follows:

The surveyor must personally make a thorough examination of each boiler, together with its superheater, superheat control, air heater and economizer, if fitted. If a boiler has not been sufficiently cleaned to allow a proper examination of pressure parts, the survey cannot be regarded as complete until this has been done. Where the construction of a boiler does not allow direct visual internal examination of the shell, drums or headers, the surveyor should be satisfied that the boiler is in a safe working condition by resorting to remote viewing instruments, ultrasonic examination, or hydraulic testing at 1.4 time the working pressure.

Internal Corrosion
Main water tube boilers. If corrosion is found in the steam and water drums of water tube boilers using a closed feed system incorporating a dearator, it indicates that the limits for the feed and boiler water condition recommended by the boiler maker and water treatment supplier are not being maintained. The Owner's attention should be drawn to operating requirements.

Boiler Repairs
Corrosion pitting which is localized along a main longitudinal or circumferential seam could be and indication of stress corrosion, with the possibility of cracks starting from the bottom of the pits. The possibility is greater when the welds have not been post weld heat-treated. If, after grinding out and proving crack free by MPI, the remaining wall thickness is less than the Rule requirements no further action need be taken after blending the profile. If deeper grinding is necessary to remove the corrosion, at the conclusion of which there is no evidence of cracks extending from the weld into the heat affected zone or parent plate, the corroded weld may be built up by welding with the finished weld being ground flush with the surrounding surface. There is to be no repair by weld build up if there is any cracking extending from the weld into the heat affected zone or parent plated. This type of defect is to be repaired by cropping and part renewing.

---

[90] DNV newsletter can be found on the internet at http://www.dnv.com/publications/classification_news/class_news_2_2004/RulesandRegulations.asp

[91] Lloyds Register Marine Division Survey Procedures Manual, May 2003, Part E, Chapter 3 - Main and Auxiliary Machinery (internal document, not publicly available)

vi) **U.S. Navy**. The navy operates a fleet of steam ships, and has many years of experience in the operation of steam ships. Navy instructions require boilers to be inspected on a periodic basis by a certified boiler inspector. Certification as a navy boiler inspector requires experience and several weeks of specialized classroom and field training. In addition, certification requires the inspector to pass the National Board of Boiler and Pressure Vessel Inspectors (NBBI) exam. Guidelines for the inspection of boilers is published in a 200 plus page document[92] that provides extensive details on various types of defects likely to be encountered at various areas of a boiler and what action, if any, the inspector must take for each type of defect encountered. In the chapter addressing drums and headers (chapter 5), the guide directs the inspector to "inspect headers and drums visually for cracking. If visual inspection shows any indication of cracks, conduct a magnetic particle (MT) inspection to confirm the presence of the defects and to determine their extent." In a table titled "inspection for cracking," the guide directs inspection of steam and water drum "welds between drum heads and tube sheets and wrapper sheets," and that "defects appear as either a distinct separation of drum heads and sheets or as fine, irregular cracks along the periphery of the weld." Further, a portion of the same table directs inspection of "general internal drum surface areas," calling attention to "random cracks may be visible in the tube or wrapper sheets, in drum heads, or at corners or knuckles in the drums. Cracking may be due to inclusions, laminations in the steel, or stress concentrations at sectional changes." A section titled "evaluation and repair deferral criteria" gives specific guidance on the treatment of conditions found. Linear defects found in the fabrication welds in heads, tube sheet, and wrapper sheet of steam and water drums are deemed to be relevant and to be subjected to exploratory grinding, and "if after exploratory grinding the defects are less that or equal to the maximum allowable grinding depth, defer further action on the remaining defects. Record defects and measurements for future evaluations."

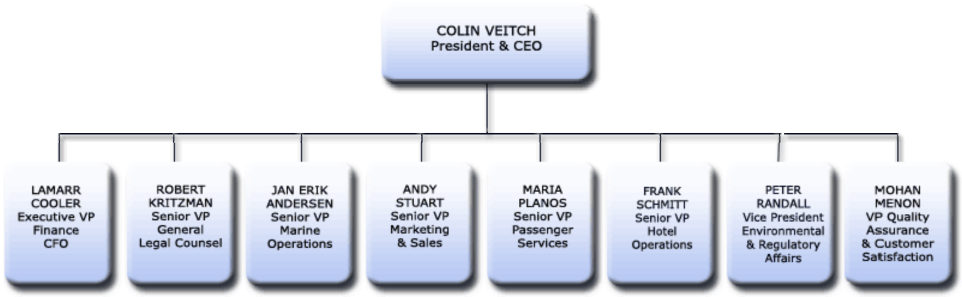
T K Roth-Roffy

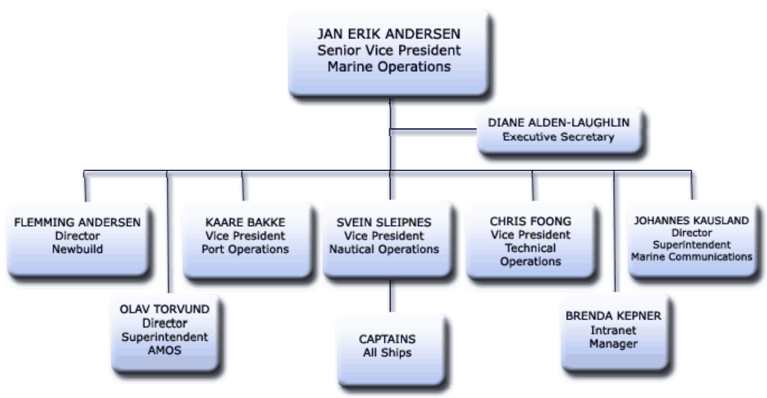
T. K. Roth-Roffy, P.E.

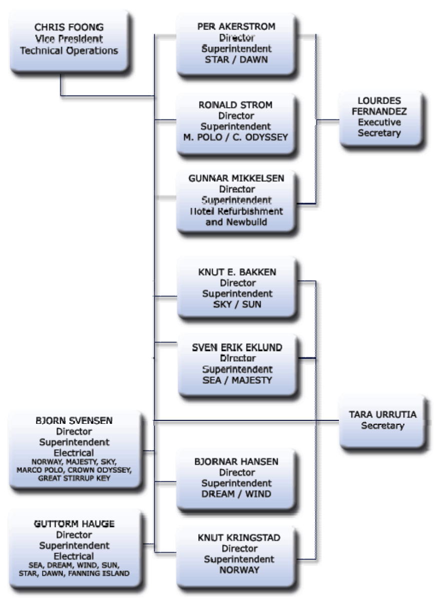
Engineering Group Chairman

[92] Technical Manual for Steam Generating Plant Inspection (Non-Nuclear), NAVSEA S9221-D2-MMA-010. Chapter 5 addresses inspection of drums and headers.

E. Additional Figures







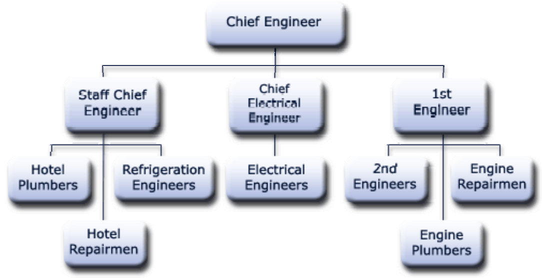


Figure 5 - NCL Organization Charts (from NCL Safety Management System)

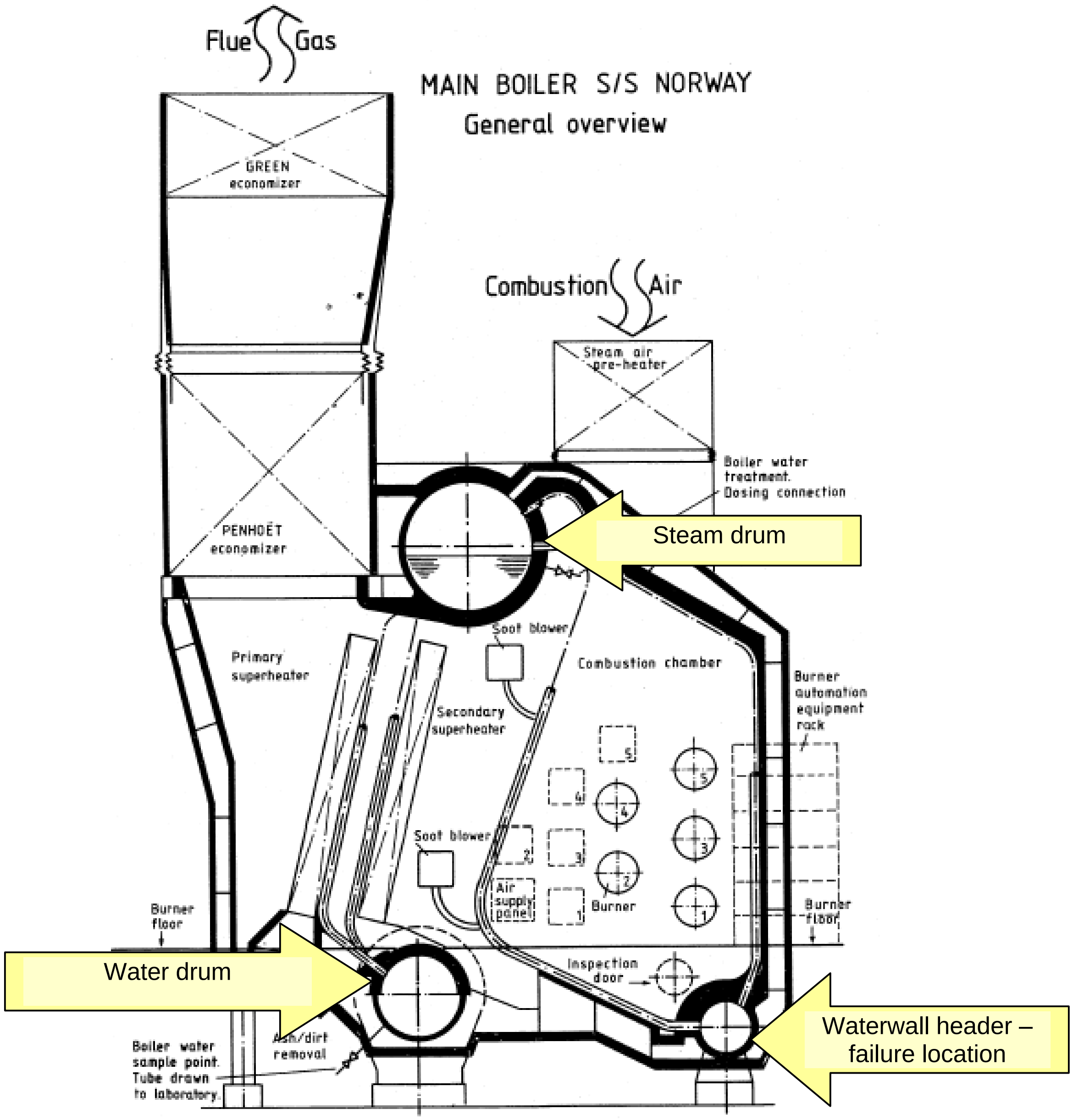


Figure 6 - Boiler cross-sectional view

F. Appendix A - Boiler Damage Report

1) UPTAKE OBSERVATIONS

a) Nr. 23 Boiler uptake transition plate located above the "Green Economizer" was noted to be displaced outboard above the inlet feed header. Sootblower elements Nr. 12 and 11 were found to be bent. Outboard Sootblower head foundation had holed the boiler casing.
b) Inboard fwd economizer support foot was found to be cracked at the weld. Subject foot is one of three noted on the inboard side of the casing, no defects were noted to the middle or aft support foot.
c) Both Green and Penhoet economizer tubes for Boiler 23 were observed to be relatively clean of soot accumulation and debris.
d) Deck grating proceeding aft between Boiler 23 and 24 was observed deformed.
e) Expansion joint bellows between the Penhoet and Green economizer sections was noted to be deformed with bellows material displaced outward of the casing. Deck grating proceeding aft between boilers 23 and 24 has been set in. In addition, the cantilever arm located above subject grating, employed to provide suspension support for the grate framing, was noted to have penetrated the outer boiler casing approximately six feet above the deck grate.

2) STEAM DRUM

a) Inboard and outboard water gage glass columns were found to have all glass elements intact. The inboard water gage column, upper glass assembly mica was observed to be white in color. Gage glass quick closing valves were operable with remote operators to the firing aisle intact.
b) Forward and aft steam drum safety valves, as well as the drum pilot actuator for the superheater safety had been removed from the pressure vessel for testing. Specific observations addressing the condition of escape relief piping were not addressed.
c) Numerous pipe hangers provided for steam and feed piping systems above the steam drum were noted to be distorted and not bearing weight of the corresponding piping application.
d) Steam drum manhole cover was removed but access not gained for inspection due to debris in the area and the restrictive personal protective clothing utilized.
e) Combustion air pre-heater supply plenum was noted to be distorted. The Upper Forced Draft Fan outlet duct flange between the before the air pre-heater and fan discharge was parted on the outboard side of the joint.

3) LOWER FORCED DRAFT FAN

a) The lower forced draft fan was found to have lifted from its foundation. The installed vibration eliminator elements for the fan end of the machine had sheared from their securing fasteners.
b) The structural box column and support beam in way of the fan end of the lower forced draft fan was observed to be distorted.
c) The access panel to the lower forced draft fan was found removed for access to the fan wheel assembly. Rotating assembly would not rotate by hand.
d) The starboard side steam atomization reducing station outlet piping was sheared from the outlet valve flange. The intact port side steam atomization reducing station piping configuration is provided as reference.
e) Deck grating and support framing system outboard of the lower forced draft fan was found to be significantly deformed. A fuel oil coating was observed on the motor controller access doors outboard of the fan assembly.

4) BOILER FRONT

a) Boiler 23 is outfitted with five Babcock "Iowa" Type register assemblies, Register Nr 1 and its associated burner throat ring had been removed to allow access to the boiler firesides.
b) Burner front outer casing had separated from the boiler roof outer casing at the upper outboard joint casing.
c) With the exception of Nr 1 burner, all installed register assemblies remained outfitted with installed burner assemblies.

d) The diffuser plate for Nr 1 register was found to be severely bent.
e) The Nr. 2 register burner coupling yoke hand wheel and threaded stem was severely bent inboard and the flame detection unit was missing from its housing.
f) The sootblower head was observed to be cracked through its casting for the Nr 1 retractable sootblower element.
g) The burner casing front was bowed out from the inner casing when viewed through the access port. The Nr. 1 sootblower tube was parted from the inner casing joint.
h) The Nr. 3 sootblower tube was parted from the inner casing joint.
i) The outer boiler front casing was displaced from the mud drum by approximately eight inches. The mud drum horse collar appeared intact in way of the upper drum region, but all securing fasteners from the collar to the inner casing in way of the lower drum section were missing.
j) The most severe deformation of the boiler front casing was observed at the lower outboard side of the burner front.

5) **REAR CASING/SUPERHEATER HEADER ACCESS**

a) The lower inboard and outboard outer casing superheater access door were found blown open. Overall, the rear outer casing was significantly displaced aft.
b) Two (2) low point superheater header drain pipes, approximately ½ inch ID, were found to be sheared from the outer casing piping connections.
c) The outer rear casing was missing all of the originally installed thermal insulation.

6) OUTBOARD AND UNDERSIDE CASING

a) The outboard side wall outer casing was significantly disfigured and displaced in a combined outboard and upward orientation.
b) The furnace inner steel floor was completely visible from the tank top. Several areas of the floor were ripped exposing some floor tube surfaces. The damaged areas correspond to the locations that tie rods between the inner and outer casing were installed.
c) The inner steel furnace floor was observed pulled outboard of the mud drum attachment exposing numerous floor tubes
d) Overall, the outboard sidewall outer casing was observed to be significantly deformed with numerous sections of displaced casing sheathing strewn about the outboard aft machinery space longitudinal area.

7) FURNACE

a) Sidewall and rearwall tubes were observed to be in relatively good condition, no significant distortion was observed.
b) Sidewall, rearwall, furnace roof refractory remained fairly well intact as did boiler furnace copings.
c) The furnace floor could not be assessed to the extent of displaced floor refractory and rubble.
d) The burner front wall was noted to be in sound condition with the exception of a castable refractory section found above atop and inboard towards the steam drum above Nr 4 register assembly, subject refractory was found on the bricked furnace floor.
e) Generating bank screen tubes appeared visually intact with no obvious distortion of installed screen tube configuration apparent.
f) For reporting purposes, it is significant to note that a thorough assessment of the furnace area proper for boiler Nr. 23 was not conducted due to structural integrity concerns; specifically, both forward and aft side wall header sliding feet assemblies were observed to be displaced vertically by approximately six inches from their corresponding foundations prior to furnace assessment.

8) WATER DRUM and WATERWALL HEADER

a) A significant section of the wrapper sheet was observed to be liberated from the header proper.
b) b) Water drum displayed no visual external defects.

9) BOILER FOUNDATIONS AND TANK TOP

a) The tank top port side aft boiler room between frames 128 and 121 were observed to be significantly depressed towards the keel in way of the area beneath Nr 23 boiler side wall header.
b) The burner front sidewall header sliding foot was raised from its foundation approximately six inches up and deflected inboard approximately three inches. All studs and nuts remained in the foundation with washers sheered and nuts deformed.
c) The waterwall header aft sliding foot was raised from its foundation approximately six inches up and deflected approximately three inches inboard. All studs and nuts remained in the foundation with washers sheered and nuts deformed.
d) Water drum foundation feet remained intact and appeared tight.
e) No boiler foot print drawing was readily available to confirm the location of the designed fixed foundation foot.

10) FUEL OIL TRANSFER AND TREATMENT

a) Outboard of the Nr 21 (fwd) and Nr 23 (aft) boilers was found to contain configurations of triple stacked fuel oil heat exchangers, heavy fuel transfer pumps, fuel oil strainers, fuel oil service pumps and boiler filling pumps. All noted pumps identified were of the vertical configuration. A hand drawn general arrangement drawing was utilized in an attempt to sight verify displaced/intact pumping equipment. Validation of nomenclature for the un-disturbed as well as disturbed equipment was not possible due to the thorough covering of the entire area with the propulsion fuel in service at the time of boiler 23 event. Pictures obtained in this area were adversely impacted by flash echoing from the oil soaked surfaces.
b) Heavy Fuel Transfer Pumps P21 and P23 (outboard Nr 21 boiler) were observed to be properly fitted to their corresponding pump/motor foundations, equally, the Aft Trimming Pump located outboard boiler 21 and slightly beneath the unused outboard starboard propulsion shaft appeared intact.
c) Fuel Oil Service Pumps P21 and P23 were noted assembled and properly identified by white phenolic nameplates a-fixed to the cognizant pump/motor structural foundation. Fuel Oil Service Pump/Motor assembly designated P25 was not located in its expected location.
d) A triple stacked fuel oil heat exchanger configuration was observed outboard of the de-activated starboard propulsion shaft from boiler 21. Similar configuration for the three tiered heat exchanger assembly outboard of boiler 23 indicated all exchangers not properly landed on their respective foundations. Specifically one heat exchanger was observed to be in a past vertical configuration, with its free end supported by the inboard shell plating. The remaining two (2) heat exchangers were detached from their proper orientation and supported by a ½ ton chain fall and sling configuration for personnel safety concerns.
e) The aft boiler filling pump, located slightly forward of Frame 121 port side appeared new as installed, all other prime movers and pump units outboard of boiler 23 aft of frame 125 could not be located utilizing the hand drawn machinery arrangement drawing as a reference.
f) An unidentified electric motor was found lodged between the duplex fuel oil strainer assembly and Heavy Fuel Transfer Pump P23 (note prime mover fan end bell provides a three inch yellow stencil as Number for subject assembly.
g) During survey of the outboard lower level area a portable dry extinguisher cylinder assembly was noted to be dis-figured and resting on its side, inboard of the fuel oil strainer assembly. No nameplate or location date was obtained due to fuel in use coating, but specific mention is provided regarding the location of the observed Portable Fire Extinguishing agent and its relationship to Class approved Life Saving Equipment locations.

11) BOILER CASING PROPER

a) Though not specifically tasked by the NTSB, this report's contributing personnel utilized two paths of ingress and exit through the excluded environmental protection zone in order to access the aft boiler room via both "B" and "C" deck port side entry.
b) An opening at "C" Deck Frame 120 was observed to be not to be equipped with a closure damper.
c) A similar vent screen was observed on "C" deck at Frame 119. This screen was blocked by a closure.

d) At Frame 128 port side "B" Deck there was found a double door accessing the upper boiler room fiddley, these doors were observed to be bowed out and could not be closed and dogged shut.

15. Debris Field

The aft starboard corner of the Aft Boiler Room had been substantially destroyed with equipment displaced and found interspersed with piping and instrumentation.

The main components on Deck 1, listed from the aft bulkhead and proceeding forwards are:

P	Boiler Filling Pump
P 27	Fuel Oil Pump
P	Fuel Oil Transfer Pump
P 21	Boiler Filling Pump
P 25	Fuel Oil Pump
P 23	Fuel Oil Pump
P 21	Fuel Oil Pump
P 23	Transfer Pump 23 for Heavy Fuel Oil
P 21	Transfer Pump 21 for Heavy Fuel Oil
P	Aft Trimming Pump

Note: at the aft end of the Boiler 23 an Emergency Feed Water Pump was being installed at tank top level. The installation was incomplete at the time of the incident.

The main components on Deck 2, listed from the aft bulkhead and proceeding forwards are:
Electrical controllers for:
Fuel Oil Pump 27
Fuel Oil Pump 25
Fuel Oil Pump 23
Fuel Oil Pump 21

Lower Forced Draft Fan for Boiler 23
Upper Forced Draft Fan for Boiler 23

Lower Forced Draft Fan for Boiler 21
Upper Forced Draft Fan for Boiler 21

Transfer Pump 23 for Heavy Fuel Oil
Transfer Pump 21 for Heavy Fuel Oil

Ventilation AF 21/23/25

G. Appendix B – Safety Valve Test Report

Date: June 10, 2003

1. Tests performed at NORSE DIESEL REPAIR shop in Miami, FL. This test was video taped by the NTSB, video tape remains on file.

2. Witnesses to testing:

   Brian Curtis- NTSB
   Carlos Paillacar- USCG
   Steinar Sjohaug- SS Norway Chief Engineer
   Oddvar Tveit- Relief SS Norway Chief Engineer
   Bjonar Hansen- SS Norway Superintendent

3. The following four valves were tested:

   1. Superheater Safety Relief Valve
   2. Drum Safety Valve
   3. 2nd Drum Safety Valve
   4. Superheater Safety Relief Pilot Valve

4. Testing procedure used was as follows:

   Valves were secured vertically in a vise. Lifting pressure was supplied from a Nitrogen cylinder, through an approximately ½ inch diameter hose, to the inlet port of the valves. Flanges and gaskets were used to seal the inlet connections of the valves, and the nitrogen hose was connected to the flange through a threaded fitting. A pressure gauge was mounted, inline with the ½ inch hose, at the nitrogen bottle's neck for observation and documentation of popping pressures. Control of the pressure to the valve being tested was obtained by manually opening and closing the cylinder shutoff valve.

5. Test Observations:

   The first valve tested was the Superheater Safety Valve (Item #1 above). Pressure was gradually applied. At 60 bar, the valve began to slowly leak by, emitting a hissing noise. There was no clearly discernible popping pressure observed for documentation purposes. The test was stopped, and the nitrogen secured at 80 bar, at which point the valve had still failed to open fully. As pressure was dropping to the valve, there was no clearly obtainable reseating pressure, as the leakage continued well past where one would expect reseating to occur.

   The second valve tested was a Drum Safety Valve (Item #2 above). Pressure was applied in a gradual manner, and as the valve before, there was no clearly defined popping pressure observed. The valve began to show signs of leaking by at 72 bar. Pressure from the nitrogen bottle was secured, and the valve reseat at 68 bar. However, this reseating was, as in the previous valves openings, not clearly defined.

   The third valve tested was the 2nd of the two Drum Safety Valves (Item #3 above). Almost immediately from the time nitrogen pressure was applied to it, it began to leak by its seating surface. By the time the test reached 12 bar, it was exhausting the nitrogen at a pace where the volume of the supply pressure was insufficient to further increase the test pressure in the valve body. The test was halted at this point.

   The fourth valve tested was the Superheater Safety Pilot Valve (Item #4). Pressure was gradually applied, and it began to slowly leak by, and emitting a hissing noise at 60 bar. We continued to gradually increase pressure to the valve, and it popped cleanly at 72 bar. At this point, the nitrogen was secured so we could ascertain a reseat pressure. As pressure decreased in the valve, a clear reseating pressure could not be established, and the valve continued to leak by its seating surface well beyond an expected reseating pressure.

H. Appendix C - Boiler Control System Test Report

REPORT – ON SITE INVESTIGATION

In connection with explosion on board the Bahamian Flag Cruise Vessel Norway on May 25, 2003, at Miami Terminal 1; NTSB Accident DCA3MM032.

Introduction

The purpose of Siemens part of the investigation was related to the burner management (BM) and safety system of boiler 23 on board SS Norway.

The BM system on board at the time of the accident is basically the same system commissioned in 1980 as part of the refurbishing of the SS France, then renamed SS Norway.

The BM is an electronic system based on Siematic C hardware, a hardware used on numerous applications in industry, shipping and offshore.

Mr. Röttingen was involved in the conversion work, but has had no connection to the ship the last 20 years. He is presently employed with Siemens.

The situation at present

The BM system is located in the engine control room which has not been affected by the incident with boiler 23. However, the local actuators, sensors and cabling have to such a degree been damaged that a full line check will not be possible. It was therefore decided to do the functional check-up by simulating the boiler inputs from sensors and operating devices in the boiler room and measure the response going out from the control room to the boiler room.

This means that the whole safety line can not be fully checked where the action of the safety device itself at the boiler is observed. However, the design of the local devices (solenoid valves) are spring operated to close if the signal fails or goes to zero (see instruction book chapter 4, drawing TC005.29).

The local devices were therefore only inspected and not observed in action.

The event log from the alarm system is not available. Only pen recorders for the most important parameters from the boilers are available.

The check procedure

The burner management is sequential. This means that one event triggers the next one and they have to be performed in a special order to fulfil the requirement of the system logic. The burner management systems checks the preconditions for the light off of the burners and sets the right devices up as the operator demands to start or stop burners. Each boiler (there are four in the boiler room) has five burners. They can be operated in any number and there are no restrictions on which burners can be in operation at the same time.

The other function of the burner management is to trigger automatic shutdown if there are parameters that could harm the boiler.

On board SS Norway the following parameters will trigger a safety shutdown of the boiler:

- Manual shutdown from engine control room
- Manual shutdown from local control station
- Forced Draught Fan failure
- Main Fuel Oil Pressure low
- Boiler Drum Low water level (2 independent water level sensors)
- Boiler Drum Pressure High
- Super heat steam pressure high
- Burner failure (no flame detection)

One shutdown parameter can be overridden at the time for verification of functionality.

A key operated switch can allow for an emergency operation of the boiler and override some safety shutdowns. However, this will not take away the following shutdown causes:

- Low water level in the drum
- Manual shutdown from ECR and local station
- Flame failure

Since the ultimate check in connection with a potential for furnace gas explosion is related to the flame failure it was decided to check out this function.

In case of flame failure there are two possibilities:

Flame failure at one particular burner will shut off the oil supply to this particular burner. There are two valves in series doing this. They are air to open and spring operated to close.

Flame failure that leaves no flame left in the boiler will in addition close the main fuel oil control valve to the boiler. This valve is sitting upstream from the burner valves.

To set up the burner management for boiler 23 in a state that relates to the boiler in operation (burner on) the following jumpers were connected:

IE4 6 to 5 Burner #3 flame on
IE3 1 to 2 Atomizing steam not low
IE3 3 to 4 Heavy fuel oil pressure not low
IE3 9 to 10 Control air pressure not low
IE3 15 to 16 FD fan not failed
IE2 9 to 10 Burner #3 oil valve open
IE2 21 to 22 Main fuel oil valve open
IE2 11 to z22 Burner #3 in operation
IE1 40 to 41 Water drum level not low
IE1 45 to 5C63 B26 Measuring fuel valves for burner #3 out signal
2C09 07 to common (M) Main fuel valve not closed
3C09 09 to common (M) Repumping off
3E5 17 to 18 Air register for burner #3 open

All references are found on Siemens drawing no. G18000-A9138-S161, ….S162, ….S165

In addition to the above jumpers it was necessary to set or reset different flip flops in the system to simulate the events leading up to the boiler in operation mode. This was one of the tricky parts of the simulation since the jumpers describe a static situation and the events leading up to the boiler in operation state is sequential.

With the removal of the flame signal jumper, the in operation flip flops (Three in series) were set in the shut off status and the signal to the fuel oil valves taken away. This means signal to shut off of fuel oil to the boiler, both the main fuel oil valve and the two valves to the burner.

Conclusion

The safety system works as intended from the control room when the flame fails in the boiler as seen by the test.

Other items

Item 1
A jumper was found in the burner management system for boiler 23. The jumper was from IEG 29 to 30. It locks out the fuel oil low temperature signal. The signal is used in connection with boiler light off as a check that the temperature is above minimum value. Too low fuel oil temperature will prevent the oil from being ignited. It has no bearing on safety. There was no similar jumper found for the other boilers.

Item 2
The pen recorders for the parameters on the boiler were examined. There was similar movement for all boilers in operation prior to the incident. The only exceptions were the fuel oil pressure and fuel oil flow for boiler 23. The signal from the transmitter is 4 – 20 mA. The supply comes from the control room. The two sensors (transmitters) are located in the exposed area. The heat could have caused damage to the cable and/or the transmitter. The signals switched back and forth between 0 and 20 mA and had therefore no meaning. Open circuit will give a 0 mA and a short circuit will give full signal.